Local Area Augmentation System
Performance Analysis/Activities Report

Report #8

Reporting Period: October 1 to December 31, 2005

Federal Aviation Administration
William J. Hughes Technical Center
Communications/Navigation Division
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Atlantic City International Airport, NJ 08405

Executive Summary

The Communications/Navigation Division of the Federal Aviation Administration's (FAA) William J. Hughes Technical Center, Local Area Augmentation System (LAAS) Test and Evaluation (T&E) Team, provides this LAAS Performance Analysis/Activities Report (LPAR). This quarterly report is the eighth such document, and for this reporting period utilizes the FAA's LAAS Test Prototype (LTP) #1[1] as the subject LAAS Ground Facility (LGF) for performance characteristics. Major LAAS research and testing activities for the reporting period are included in summary form for a brief snapshot of LAAS Technical Center program directives, and related technical progress.

LTP #1 is a government-owned suite of equipment located on the Air Operations Area (AOA) of the FAA William J Hughes Technical Center at the Atlantic City International Airport (ACY). The LTP is completely operational and is utilized for flight-testing, in addition to data collection utilized in this report.

The LTP is the FAA's primary LAAS Research and Development (R&D) tool and is used to characterize and test performance of a typical LAAS installation in an operational airport environment. The LTP was designed with testing in mind, and its testing legacy continues to this day. As an FAA test system, the LTP is utilized in limited modified configurations for various test and evaluation activities. This system is capable of excluding any single non-standard reference station configuration from the position solution. The performance reporting of the system is represented only from LAAS standard operating configurations. Special configurations and maintenance details are included in a separate section within this report.

Table 1 summarizes observations of the major performance parameters used as a representation of accuracy and integrity for this reporting period. All units are in meters.

Parameter	Maximum Observation	Minimum Observation
Vertical Protection Level (VPL)	3.693	1.51
Horizontal Protection Level (HPL)	2.608	1.186
Clock Error	16.487	3.09
Dilution of Precision (DOP) (VDOP) (HDOP)	 2.495 1.832	 0.945 0.724

Table 1: Key Performance Summary

[1] LTP # 2 is deployed in Rio De Janeiro, Brazil where Government LAAS flight-testing is being conducted, while critical ionospheric ground data is being collected.
LTP # 3 is located on the FAA controlled area of the Atlantic City International Airport. This system is configured for multiple purpose testing.

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1. Introduction

The FAA is actively involved in the development of LAAS performance requirements and architecture, and maintains a LAAS Test Prototype (LTP) to evaluate new concepts and resulting performance benefits. The LAAS T&E team utilizes a number of tools and methods to analyze system performance. These tools include a raw data analysis technique known as Code Minus Carrier (CMC), to closely observe errors down to a single Satellite Vehicle (SV) on a single Reference Receiver (RR). Additional system level techniques are mature enough to display key system performance parameters in real time. The LAAS T&E team has adapted the LAAS software to actively gather these key parameters for the data plots to be presented in this report.

Objectives of this report are:

a) To briefly introduce LAAS concepts and benefits.
b) To provide a LTP (LAAS Test Prototype) system level overview to aid in comprehension for persons unfamiliar with the material.
c) To present Global Positioning System (GPS) constellation, and SV availability at ACY, and any unfavorable bearing on overall system performance.
d) To briefly document LAAS related testing and maintenance activities.
e) To present the LAAS system's ability to augment GPS by characterizing key performance parameters.
f) To provide a key performance summary and full performance plots.

2. Aerial Photograph of LTP at ACY with Overlay

Figure 1 is an aerial shot of the FAA's LTP taken during a LAAS flight test. This valuable FAA R&D tool provides a valid representation an actual LAAS installation in an operational airport environment. The major system sites are identified.

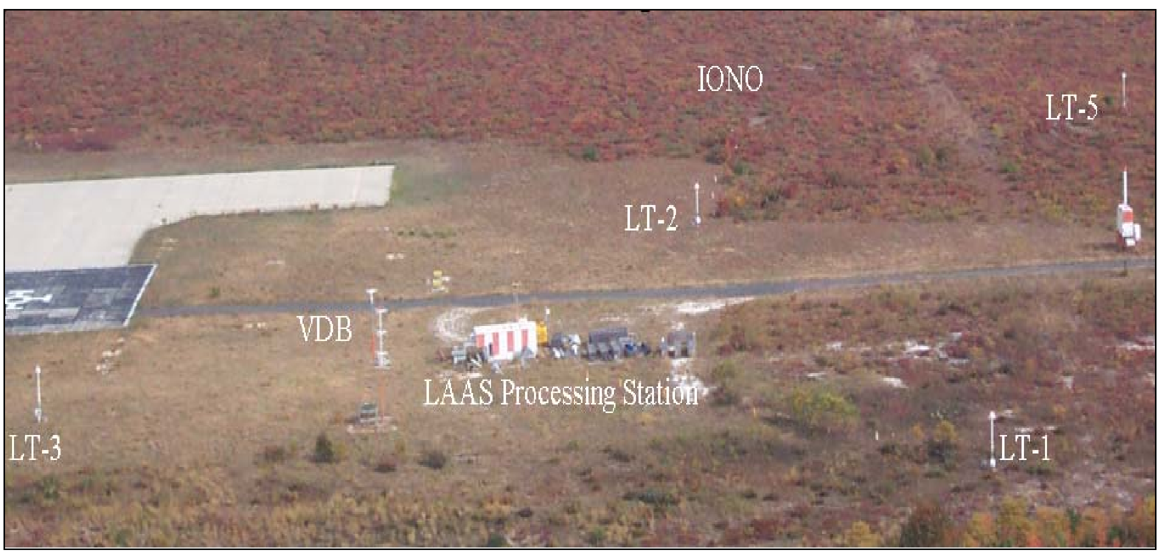


Figure 1: Aerial of LTP at ACY

3. LAAS Overview

This section is provided for persons unfamiliar with LAAS concepts and components. This brief overview is intended solely as an introduction.

A LAAS is essentially an area navigation system with its primary function being a precision landing system. The LAAS provides this capability by augmenting the Global Positioning System (GPS) with differential corrections.

3.1 LAAS Operational Overview

A Local Area Augmentation System (LAAS) ground facility (LGF) includes four Reference Receivers (RR), four RR antenna (RRA) pairs, a Very High Frequency (VHF) Data Broadcast (VDB) Transmitter Unit (VTU) feeding an Elliptically Polarized VDB antenna. These sets of equipment are installed on the airport property where LAAS is intended to provide service. The LGF receives, decodes, and monitors GPS satellite pseudorange information and produces pseudorange correction (PRC) messages. To compute corrections, the ground facility compares each pseudorange measurement to the range measurement based on the survey location of the given RRA.

Once the corrections are computed, integrity checks are performed on the generated correction messages to ensure that the messages will not produce misleading information for the users. This correction message, along with required integrity parameters and approach path information, is then sent to the airborne LAAS user(s) using the VDB from the ground-based transmitter. The integrity checks and broadcast parameters are based on the LGF Specification, FAA-E-2937A, and RTCA DO-253A (Airborne LAAS Minimum Aviation Performance Standards or MOPS).

Airborne LAAS users receive this data broadcast from the LGF and use the information to assess the accuracy and integrity of the messages, and then compute accurate Position, Velocity, and Time (PVT) information using the same data. This PVT is utilized for the area navigation (RNAV) guidance and for generating instrument landing system (ILS)-look-alike indications to aid the aircraft on an approach. A developmental airborne system that is capable of this type of navigation is referred to as a Multi-Mode Receiver (MMR). The MMR coupled with a LAAS can generate mathematical paths in space to any number of waypoints and touchdown points in the local area.

One key benefit of the LAAS, in contrast to traditional terrestrial navigation and landing systems (i.e. ILS, MLS, TLS, etc.), is that a single LAAS system can provide precision guidance to multiple runway ends, and users, simultaneously. Only the local RF environment limits this multiple runway capability. Where RF blockages exist Auxiliary VDB Units (AVU) and antennas can be added to provide service to the additional runways. This capability can also be built upon to provide service to adjacent airports.

3.2 LAAS Simplified Architecture Diagram

Figure 2 is provided as an illustration of LAAS operation with major subsystems, ranging sources, and aircraft user(s) included.

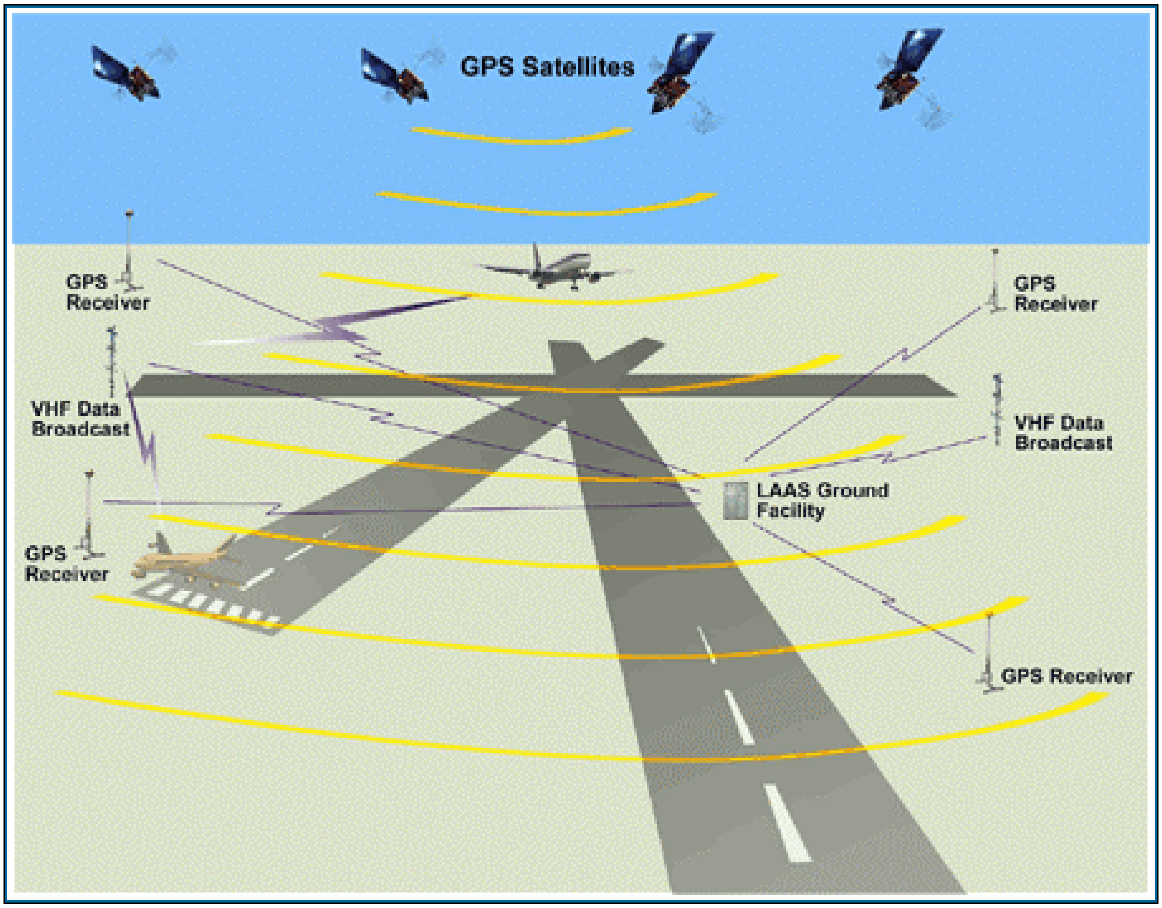


Figure 2: LAAS Simplified Architecture Diagram

4. GPS Constellation from ACY

Satellite Vehicle (SV) availability and constellation geometry has an impact on overall LAAS system performance. This section provides a snapshot of the expected constellation for the reporting period. GPS Notice Advisory to Navstar Users (NANUs) are known SV outages events that are excluded from these plots, but are included at the end of this section.

4.1 SV Availability Plot

ACY has a fairly robust available constellation expected throughout most of the sidereal day with limited periods where the observable SVs are forecasted to drop below nine.

Figure 3 is an SV availability prediction graph representative of the reporting period. The graph does not account for any NANUs following the generation of the plot. It also does not include the WAAS geo-stationary satellite.

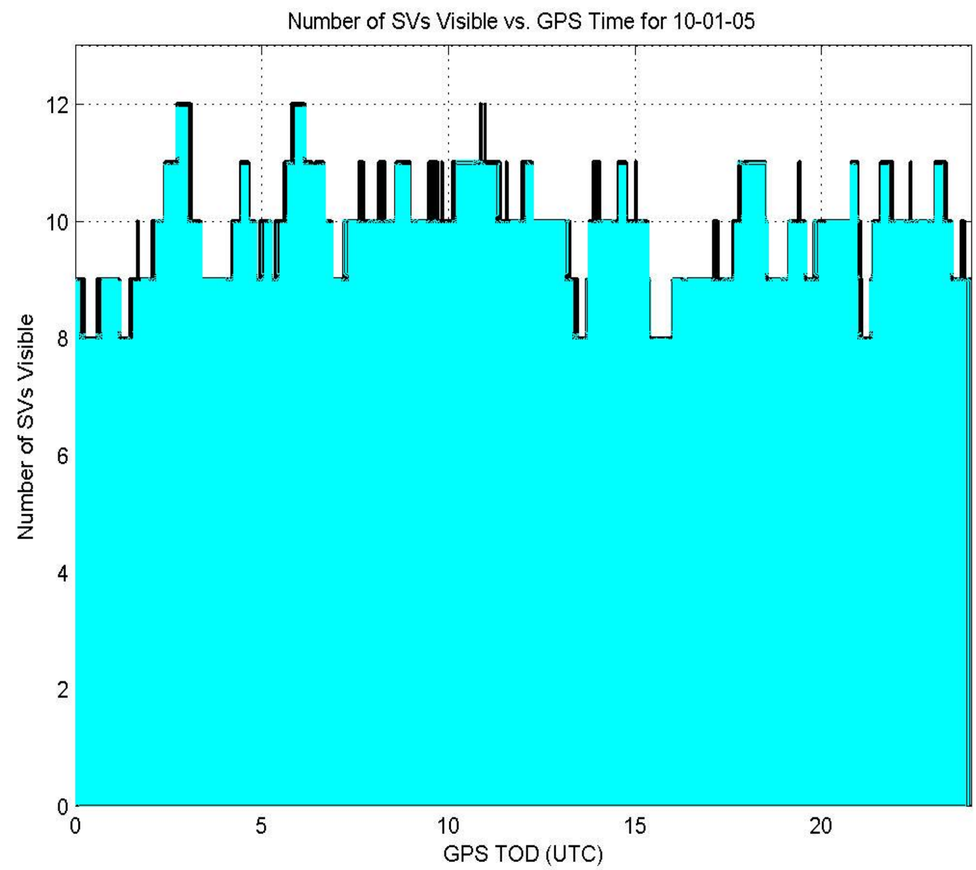


Figure 3: SV Availability at ACY

4.2 SV Elevation Plot

SV elevation and the resulting geometry have a bearing on the overall LAAS performance. The LAAS reference station antennas are of a dual segment design and are referred to as the Integrated Multi-Path Limiting Antenna (IMLA). The two segments (upper and lower) have patterns that overlap each other centered at approximately 29 degrees elevation with an overlap of about 13 degrees above and below this point. At least one common SV must be tracked by the two segments in order for the LAAS software to calculate the hardware bias inherent in such systems. The more common satellites tracked, the better the estimation of the hardware bias. The elevation of the Wide Area Augmentation System (WAAS) geo-stationary satellite from ACY is approximately 39 degrees, and can serve as a steady ranging source available for the bias calculation.

Figure 4 is an SV elevation prediction graph representative of the reporting period. The graph does not account for any NANUs following the generation of the plot. The graphic also does not include the WAAS SV(s).

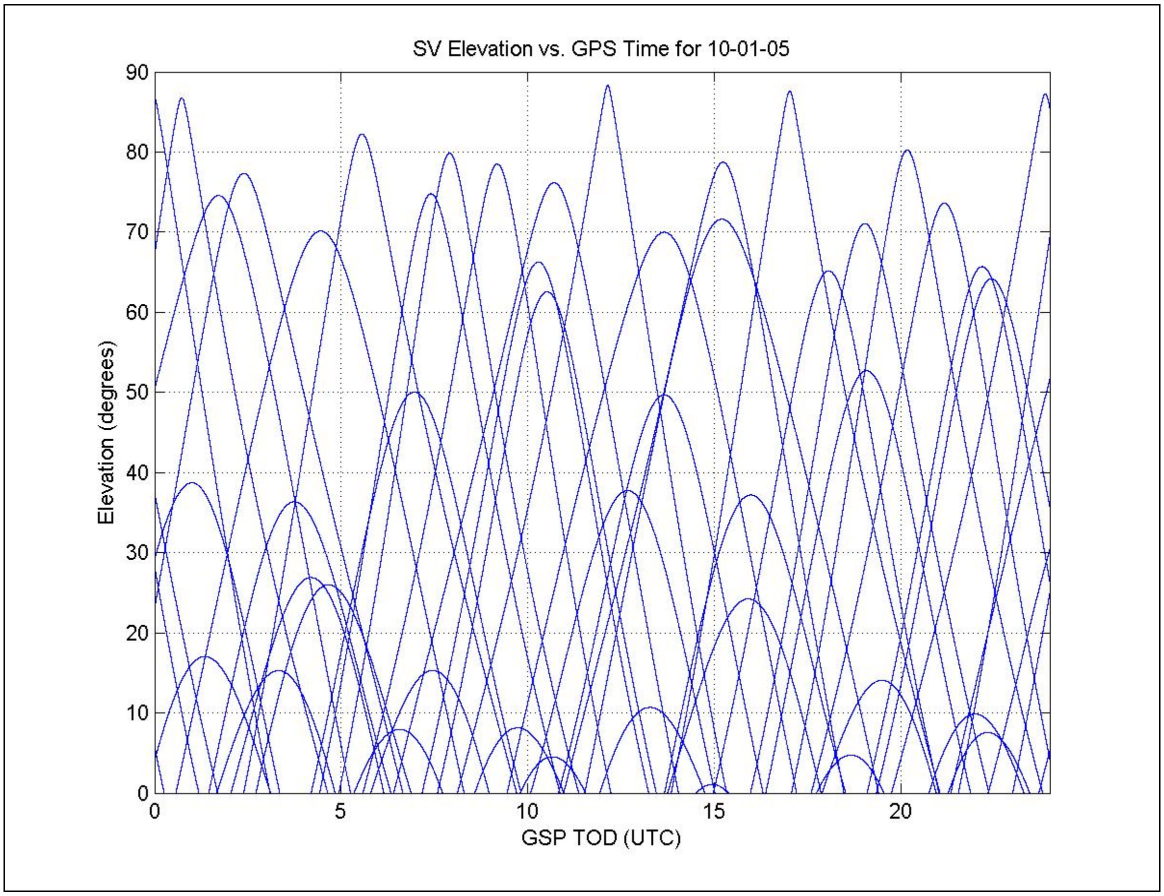


Figure 4: SV Elevations at ACY

4.3 Notice Advisory to Navstar Users (NANUs)

The GPS constellation is designed to provide adequate coverage for the continental United States for the majority of the sidereal day. A NANU is a forecasted or reported (un-forecasted) event of GPS SV outages, and could cause concern if the SV outage(s) affects minimum required SV availability or causes a period of no common satellites in the overlap region of the IMLA antenna.

NANUs that caused an interruption in service (where Alert Limits are exceeded) will be highlighted within NANU summary (see **Table 2**). Although such an interruption is unlikely, the LAAS T&E team closely tracks the NANUs in the event that post-data processing reveals a rise in key performance parameters. Any highlighted NANUs will include additional data plots (section 8.4), and accompanying narrative in the "Performance Summary" section (8.3).

The NANUs provided include only definitive SV outages and decommissions. An "Outage Summary" provides the actual period of the forecasted SV outage. An "Unusable" provides the same information for an un-forecasted SV outage, or a previous "Unusable UFN" (Until Further Notice). An occasional "Usable" will be seen for SVs that were previously "Unusable" or "Unusable UFN". An "Unusable UFN" is an SV outage that remained unusable Until Further Notice (no forecast on return to "Usable" status). **Table 2** provides actual SV outages for the reporting period.

NANU #	NANU Type	PRN	Date Begin	UTC Begin	Date End	UTC Ended
2005128	Outage Summary	PRN-04	10/04/05	14:47	10/04/05	19:39
2005130	Outage Summary	PRN-21	10/13/05	02:17	10/13/05	09:05
2005132	Outage Summary	PRN-25	10/20/05	02:12	10/20/05	10:16
2005134	Unusable	PRN-31	04/14/05	16:34	10/24/05	22:42
2005135	Decommission	PRN-31	10/24/05	22:42	N/A	N/A
2005140	Unusable	PRN-09	10/31/05	15:06	11/15/05	00:26
2005145	Outage Summary	PRN-06	11/21/05	14:12	11/21/05	21:53
2005148	Outage Summary	PRN-15	12/01/05	19:24	12/02/05	02:09
2005153	Outage Summary	PRN-30	12/15/05	13:48	12/15/05	20:09
2005155	Usable	PRN-17	12/16/05	23:30	N/A	N/A
2005160	Unusable	PRN-09	12/19/05	14:49	12/24/05	07:38
2005157	Outage Summary	PRN-26	12/20/05	14:37	12/20/05	19:27
2005159	Unusable	PRN-25	12/23/05	22:20	12/24/05	06:52

Table 2: NANU Summary

5. Configuration, Monitoring, and Testing

This section provides a description of the LTP system, monitoring, and testing configurations in terms of hardware and software for the reporting period. Since the LTP is the FAA's primary R&D tool for LAAS these sections could vary somewhat between reporting periods. The majority of these changes will likely first emerge in Section 5.5.

5.1 Master Station

The LTP Master Station or Processing Station is a complex collection of hardware and related interfaces driven by a custom software program. The master station hardware and software operations are described in this section.

5.1.1 Master Station Hardware

The Master Station (or processing station) consists of an industrialized Central Processing Unit (CPU) configured with a Unix type real time operating system. The CPU is configured with a SCSI I/O card for mounting an external hard drive. This hard drive collects all raw reference station GPS data messages in parallel to the processing of those messages. The drive is also used to collect debugging files and special ASCII files utilized to generate the plots found in this report. These collected files are used for component and system level performance and simulation post processing.

The CPU is also configured with a multi-port RS-232 serial card to communicate in real time with the four reference stations and to the VDB. The reference stations continuously output raw GPS messages to the CPU at a frequency of 2 Hz. Data to and from the reference station fiber lines is run through media converters (fiber to/from copper), which provides a RS-232 serial signal to the CPU's multi-port serial card. The CPU then generates the LAAS corrections and integrity information and outputs them to the VDB.

The VDB Transmitter Unit (VTU) is capable of output of 150 watts and employs a TDMA output structure that allows for the addition of auxiliary VDBs (up to three additional) on the same frequency for coverage to terrestrially or structure blocked areas. The LTP's VTU is tuned to 112.15 MHz and its output is run through a band pass, and then through two cascaded tuned can filters. The filtered output is then fed to an elliptically polarized three bay VHF antenna capable of reliably broadcasting correction data the required 23 nautical miles.

Surge and back-up power protection is present on all active master station components.

5.1.2 Master Station Software

Ohio University (OU) originally developed the LAAS code through a FAA research grant. Once the code reached a minimum of maturity, OU tested and then furnished the code to the FAA (circa 1996). It was developed using the C programming language under the QNX operating system. QNX was chosen because of its high reliability and real-time processing capability. This LTP code has been maintained by the LAAS T&E team since that time and has undergone numerous updates to incorporate evolving requirements and hardware. The current internal master station software version is 3.0.

The code stores the precise survey data of the four LAAS reference station antennas (all eight RRA segments). The data structures are initialized, input files are opened, and the output files are created. Messages are received via four serial RS-232 connections, which are connected to four GPS receivers. The program cycles through the serial buffers and checks for messages, if one is found it gets passed to a decoding function. From there it is parsed out to functions according to message type and the information from the messages will be extracted into local LTP variables. Once the system has received sufficient messages the satellite positions are calculated in relation to the individual reference receivers. Next the system corrects the phase center measurements for the stacked dipole antenna array and converts the measurements from the individual reference locations to one simple reference location. The High Zenith Antenna (HZA) and dipole measurements are then combined to form one virtual reference receiver at the reference location. Then the integrity and protection equations are processed which produces the alert levels for the LGF. Next the position solution and reference position is calculated. Messages are then encoded and sent to the VDB via a RS-232 connection. Each of the three message types are encoded separately and sent according to DO-246B standards. The final step in the LGF software is to update the graphics and respond to the user inputs. At this point the software checks for problems that could have occurred during the processing and will either stop the program, or restart the cycle by reading the serial data.

5.2 Reference Stations

There are four reference stations included in the FAA's LTP as required in the LAAS specification. The LTP's reference stations are identified as LAAS Test (LT) sites; there were originally five LT sites (1 through 5) but #4 was abandoned in favor of the remaining four LT sites (see **Figure 1**).

Each reference station consists of 2 major component systems. The first is a hybrid GPS antenna, known as an IMLA. The second is the reference receiver and transmit system.

5.2.1 The Integrated Multipath Limiting Antenna (IMLA), and the Multipath Phenomenon

The IMLA (see **Figure 5**) is a hybrid, two receiving segment, GPS antenna that is approximately 12 feet in height and 100 pounds in weight. The two segments (top and bottom) have specially designed overlapping patterns and high Multipath rejection.

Figure 5: The IMLA Antenna

Multipath is a phenomenon, which is common to all Radio Frequency (RF) signals, and is a particular concern in differential GPS navigation (i.e., LAAS). The two major types are Reflected and Diffracted Multipath. Diffracted Multipath is the bending of a signal around the edges and corners of structures and other obstructions. Reflected Multipath is the bouncing of the signal on any number of objects including the local water table.

Signals that bounce off the water table is often referred to as Ground-Bounce Multipath. In all cases the path length is increased. This path length is critical in GPS since the ranging is based on signal's Time of Arrival (TOA). Multipath can cause a standard GPS system to track an indirect signal rather than the direct GPS signal. This causes a pseudorange error, for the SV being miss-tracked, in the amount of the indirect signal's additional path length. This pseudorange error will translate directly in to the position solution.

Siting criteria developed around the IMLA antenna mitigates the diffracted and above ground level Reflected Multipath. The IMLA pattern design serves to mitigate the Ground-Bounce Multipath.

The bottom segment, the most critical component of the IMLA, is a 14-element stacked dipole array, which is used to include SV measurements from 5 to 40 degrees in elevation. Signals from low elevation satellites are generally lower in power and more susceptible to ground bounce Multipath, which enter conventional GPS antennas from below 0 degrees. The measurement error caused by the Multipath reflection is proportional to the ratio of the signal strength of the desired direct signal path to the strength of the undesired reflected path. The stacked dipole array is designed with a high gain lobe in the direction extending from 5 to 30 degrees, and is reduced by 35 dB at –5 degrees, providing a strong desired to undesired ratio. The result is a limit on pseudorange measurement errors on the order of 0.3 meters.

The top segment, referred to as a Multipath Limiting High Zenith Antenna (MLHZA, or HZA for short), is a two element cross-v dipole used to include SV measurements from 40 to 90 degrees in elevation. This HZA is mounted on top of the stacked dipole array with a feed that runs inside the null chamber (center) of the 8-foot tall bottom segment. The HZA provides at least 20 dB of direct to indirect pattern isolation.

5.2.2 Reference Station Receive and Transmit System

At the heart of the LTP's four reference stations is a dual deck, 12-channel (24 total), narrow correlator GPS receiver tied to a common clock. The dual deck design accommodates the IMLA's two feeds, while the common clock ensures that the pseudorange measurements on both decks are taken simultaneously. A final calibration in the Master Station software is performed using an SV that is common to both decks which removes any remaining hardware biases. The current version of the receiver firmware is 7.51s9.

Data to and from the reference stations are put on fiber lines, which run through media converters (fiber to copper), which provide a RS-232 serial signal to the receiver communications port and master station CPU.

Surge and back-up power protection is present on all active reference station components.

5.3 Field Monitoring Stations

The LTP's operation and performance is closely monitored with several dedicated systems. This section outlines the two major monitoring tools that provide an instantaneous performance indication as well as post data processing capability.

Raw monitoring station data collected is useful for observing variations in the differential position since the position can be compared to the survey position of the fixed GPS antenna. Also, it provides a continuous position calculation reference in the absence of actual flight-testing.

5.3.1 Multi-Mode Receiver (MMR) Station

The first LTP monitoring station is a static ground based MMR system. The LAAS T&E team maintains an MMR on a precise surveyed GPS antenna to monitor ground station performance and to evaluate MMR software updates. The MMR drives a dedicated Course Deviation Indicator (CDI). The CDI is a cockpit instrument that indicates fly left/right and up/down information with respect to the intended flight path. The CDI should always be centered when the MMR is tuned to the virtual runway that coincides with the antenna's survey position. The version of MMR firmware for this reporting period is Flight Change (FC) 21.

5.3.2 LTP User Monitoring Station

The second monitoring station is an LTP airborne subsystem (LTP Air), which is used as a static user platform. The LTP Air is a prototypical mock-up with navigational capabilities similar to that of the MMR. The LTP Air, however, provides more configuration flexibility than the MMR and serves well as an R&D tool. These systems are used for actual flight-testing, and for MMR update verification or troubleshooting. This dedicated LAAS field monitor, as the MMR, is placed on a precise surveyed GPS antenna. Data is collected in 24-hour intervals without interruption and is used to post evaluate system navigational performance. Live data is also fed via a wireless network and is available via the Internet. This data is displayed in graphic form and provides the user a hourly performance history glimpse. All major performance parameters, available to an airborne user, are displayed. The web address for this live service is: http://www.gps.tc.faa.gov/acylaas1.asp

The LTP Air system is the LTP's primary performance field monitoring tool. The operational configuration of this system is briefly described in the following text. The custom program initializes all the variables, sends the initialization commands to the VHF Data Link (VDL), and opens up the necessary files. The GPS receiver and VDL are connected to a multi-port RS-232 serial card, which multiplexes the inputs and connects to the computer. The messages are then parsed out according to the type, and processed accordingly. The GPS messages are then split into the different GPS message types (range, ephemeris, clock...etc) and the VDL messages are separated into each of the DO-246B LAAS message types and decoded. Next the satellite position is calculated using the range and ephemeris messages from the GPS measurements. The position of the aircraft is determined and a differential position is calculated based on the measurements from the LGF. Protection levels are calculated for the aircraft and compared to current threshold alarm levels while the satellite measurements are also checked for errors.

To drive the LTP Air's Course Deviation Indicator (CDI), an output message is constructed and is sent via the RS-232 card to an analog conversion unit. The display screen is updated to reflect the new data, and the user inputs are processed. If the program continues with no errors or user input to terminate the program, it retrieves another message from the serial buffer and begins the process again. The LTP airborne internal RCS version number for this reporting period is 1.8.

5.3.3 Position Domain Monitor (PDM) Station

Figure 6: PDM Station

The Position Domain Monitor (PDM) station (**Figure 6**) at ACY is located at the approach end of runway 13, and is just outside of the aircraft movement area (red sign on left of **Figure 6**). The location was carefully chosen to provide not only a long baseline (2330 meters) from the LTP, but also a best-case proximity to the final approach and runway touchdown point. This location therefore provides an excellent representation of what signals (GPS and VDB), constellation, and conditions a user would be experiencing on the landing portion of their approach.

The PDM is a GPS LAAS monitor of the LTP system. It incorporates the transmitted LTP corrections through a VHF receiver, along with the position it generates from an L1 frequency GPS RX, a Novatel Millennium, which gathers GPS data through a choke-ring antenna. The present architecture also includes a dual frequency receiver, a Novatel OEM4, which is hooked up to a Trimble ground plane antenna. This allows for calculating of many errors and biases, including CMC in real-time.

The main goals of the PDM monitor is to verify errors in the LTP are below the threshold set in the MOPS before this information is broadcast, and that the user's position errors are within a safe range before that information is used.

The PDM requires a minimum of 6 SVs for proper functionality The PDM uses the satellite constellation and takes into account every possible combination of 6 SVs available to the user. The worst 6-SV constellation, according to the MOPS, would be thrown out of the calculations. With this geometry, surveyed locations at the PDM are assessed.

The PDM includes a Minimum Satellite Configuration Constraint. In a 4 satellite minimum configuration, an approach cannot be begun if in that 4-satellite configuration, one of the satellites is expected to set before the approach is finished. However, a 4-satellite configuration is allowed as a "degraded" mode. Also included is a Critical Satellite Limit, which are satellites whose loss from the present constellation would cause the PL to exceed the AL. In this constraint, for an airborne user to begin approach, there must be fewer critical SVs in the current geometry than the critical satellites limit. Satellites that set during approach do not count towards the minimum satellite configuration. The current software is pdm-20050517.tar.gz.

5.4 L1/L2 Ionospheric (IONO) Station

A separate, but equally important, station is maintained at the FAA's LTP to conduct, centimeter level post processing performance analysis down to a single SV observable on a single reference antenna segment.

This station is referred to as the IONO (short for ionospheric) station (see **Figure 7**). The name is largely due to the purpose of observing the ionospheric propagation delay, as well as other path delays. The L2 carrier observable (L2 code is unobservable for civilian use) is useful in determining propagation delays in the L1 carrier due to the frequency difference in L2. The L1 frequency is centered at 1575.42 MHz, while the L2 center is at 1227.60 MHz.

Since both signals (L1 and L2) originate from the same point and time the difference in the signal's arrival times can be used to extrapolate the actual path delay. The determined delay covers the ionosphere path as well as multi-path and other delays. This total delay, due to the signal path length, and short baselines, can be applied to all 8 RRA segments. See Section 8.6 Code-Minus-Carrier (CMC) area for further detail on where the IONO data is applied.

The IONO station can also serve as a full time L1/L2 reference station for local survey work and precise aircraft tracking processing (aka Truth). Both activities require a static L1/L2 data collection setup on a known (surveyed) point. This static L1/L2 station data can then be merged, after the fact, with the dynamic (aircraft) data or the unknown static (survey) point data to determine precision aircraft path or survey position figures.

Figure 7: ACY LAAS IONO Station Antenna (with IMLA)

5.5 Testing Activities

The LAAS T&E team is responsible for verifying the performance of experimental LAAS hardware and software. Any changes in configuration, or degradations in performance, are captured and rigorously analyzed. This section outlines testing activities for the reporting period

5.5.1 Terminal Area Path/Procedure (TAP)

The LAAS, as a precision RNAV system, has built in specifications and standards for the capability of executing complex procedures and approaches. These types of procedures include, but are not limited to, curved approaches, approaches other than ILS look-alike (3 degree straight-ins), and ground based navigation (taxiing).

The LAAS T&E software team modified the existing LTP (Heliport System) software to transmit TAP data for two runways at Atlantic City International Airport. TAP data for R/W 13 and R/W 4 was imported into the LTP database and tested using a Rockwell Collins MMR. New Runway Path Data Selector (RPDS) numbers were assigned to these approaches so that the pilot could “tune” in the approach. Now because of the unlinked TAP procedures, the ground system closely resembles the new version of the MOPS (DO-246C).

5.5.2 The Memphis Plan Activities

The Memphis Plan activities began in April 2005. The Memphis plan involves a number of organizations including the FAA, FedEx, Honeywell Incorporated, Rockwell Collins, Boeing, and a number of other key players and authorities.

The Memphis Plan supports the FAA's current Flight Plan for 2005-2009. The Flight Plan's goals of increased safety and greater capacity directly relate to the work planned for Memphis. The operational implementation and data collection efforts in Memphis will support the FAA's mission to "Provide the safest, most efficient aerospace system in the world," because this work will help to determine ways to reduce pilot and controller communications and allow for improvements to system and airspace management. Because the efforts in Memphis involve several industry participants and the Federal Express (FedEx) Corporation, this plan also supports the FAA's vision to "Improve continuously the safety and efficiency of aviation, while being responsive to our customers and accountable to the public".

The Memphis Plan is part of the overall Local Area Augmentation System (LAAS) Implementation Team Plan that was developed to support the current research and development activities of the LAAS program. This plan is part of the approach to move operational implementation tasks forward in conjunction with the technical development of the ground station. In support of the technical plan, the LAAS Operational Implementation Team (OIT) will work with industry to gain as much operational experience as possible in anticipation of the certification of a LAAS ground station.

5.5.2.1 Technical Center's Role in The Memphis Plan

The LAAS Program Office has entered into a contract with the Honeywell Corporation to upgrade the current Memphis based Beta LAAS to a provably safe integrity prototype system. The Tech Center is serving as the program office's engineering clearing house for all technical issues and ground station data collection efforts associated with upgrading the Beta LAAS system located on the Memphis-Shelby County Airport Authority property. The actual Beta system belongs to Honeywell Corporation and is leased to FedEx. As the LAAS Program Office's technical representative, the Tech Center will ensure Honeywell complies with the technical specifications and terms of the Beta LAAS upgrade contract.

5.5.2.2 Memphis Beta LAAS Performance Monitor Station

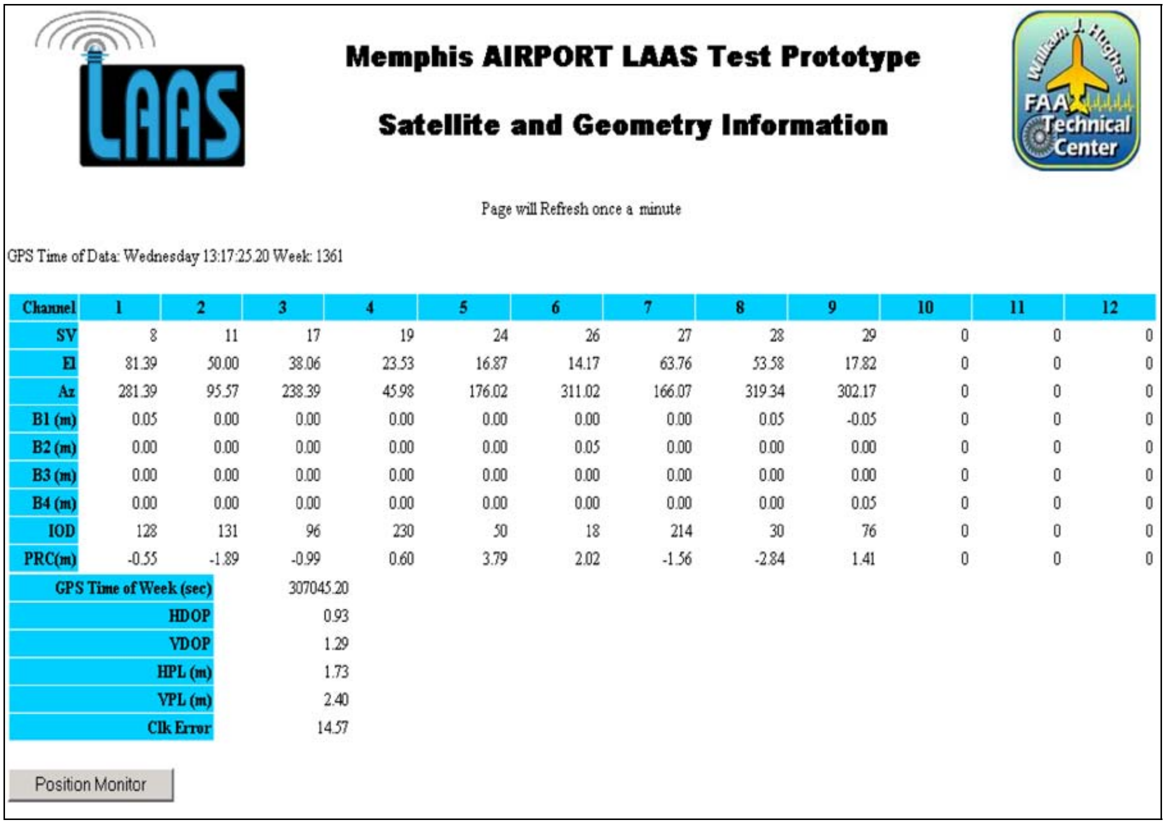
The LAAS T&E team decided early on in the planning of this effort that a dedicated fixed LAAS SIS performance monitoring station was required at Memphis. The Monitoring station is basically a stationary user platform (airborne type user) with enhanced data collection, and streaming data capabilities (for live web based performance outputs). Several requirements needed addressing before deployment, which included: a suitable AOA characteristic installation site (Hangar 12), a dedicated T1 installation, host organization (FedEx) and support personnel coordination, detailed specifications/ agreement, and permission to install such a system from the airport and FedEx.

Deployment of the Memphis monitoring station began during the week of July 11th 2005, and was fully installed (T1/Network portion) by August 17th 2005. The infrastructure installation (**see Figure 8**) for the monitor system (stable GPS antenna/feed and platform, tuned VHF antenna/feed, power, etc), installation of the support hardware (GPS receiver, computer peripherals, power protection, RF feeds/filters, etc), and a precision survey of the GPS antenna was conducted in July '05. The monitor CPU/VDB, and networking hardware was installed and configured in August '05.

Figure 8: Memphis Monitor GPS Sensor Station

Development of a web-based display, which gives a once-a-minute output of the Memphis LAAS Satellite and Geometry information, and calculated user position error (based on difference from the GPS antenna's true position), began during September'05. This live service is available at http://www.gps.tc.faa.gov/memlaas.asp. **Figure 9** provides a screen shot example of the web page, which displays the reported overall performance (titled "Satellite and Geometry") of the Honeywell LAAS station in its current configuration. **Figure 11** provides a screen shot example of the "at a glance" scrolling graphic of the Memphis Positioning Performance available through the "Position Monitor" button at the bottom of the "Satellite and Geometry" web page.

Detailed raw monitoring station data analysis also began in September '05. The FAA has developed custom data plot generating software to display all relevant data collected by the performance monitoring station in Memphis. These plots are numerous and include; ECEF X-Y-Z error (see **Figure 10**), clock error, HPL and HDOP, VPL and VDOP, horizontal error, vertical error, SVs available (air/ground), and various VDB parameters.



Memphis AIRPORT LAAS Test Prototype

Satellite and Geometry Information

Page will Refresh once a minute

GPS Time of Data: Wednesday 13:17:25.20 Week: 1361

Channel	1	2	3	4	5	6	7	8	9	10	11	12
SV	8	11	17	19	24	26	27	28	29	0	0	0
El	81.39	50.00	38.06	23.53	16.87	14.17	63.76	53.58	17.82	0	0	0
Az	281.39	95.57	238.39	45.98	176.02	311.02	166.07	319.34	302.17	0	0	0
B1 (m)	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.05	-0.05	0	0	0
B2 (m)	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0	0	0
B3 (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0
B4 (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0	0	0
IOD	128	131	96	230	50	18	214	30	76	0	0	0
PRC(m)	-0.55	-1.89	-0.99	0.60	3.79	2.02	-1.56	-2.84	1.41	0	0	0

GPS Time of Week (sec)	307045.20
HDOP	0.93
VDOP	1.29
HPL (m)	1.73
VPL (m)	2.40
Clk Error	14.57

Position Monitor

Figure 9: Memphis Performance Monitor Web Page

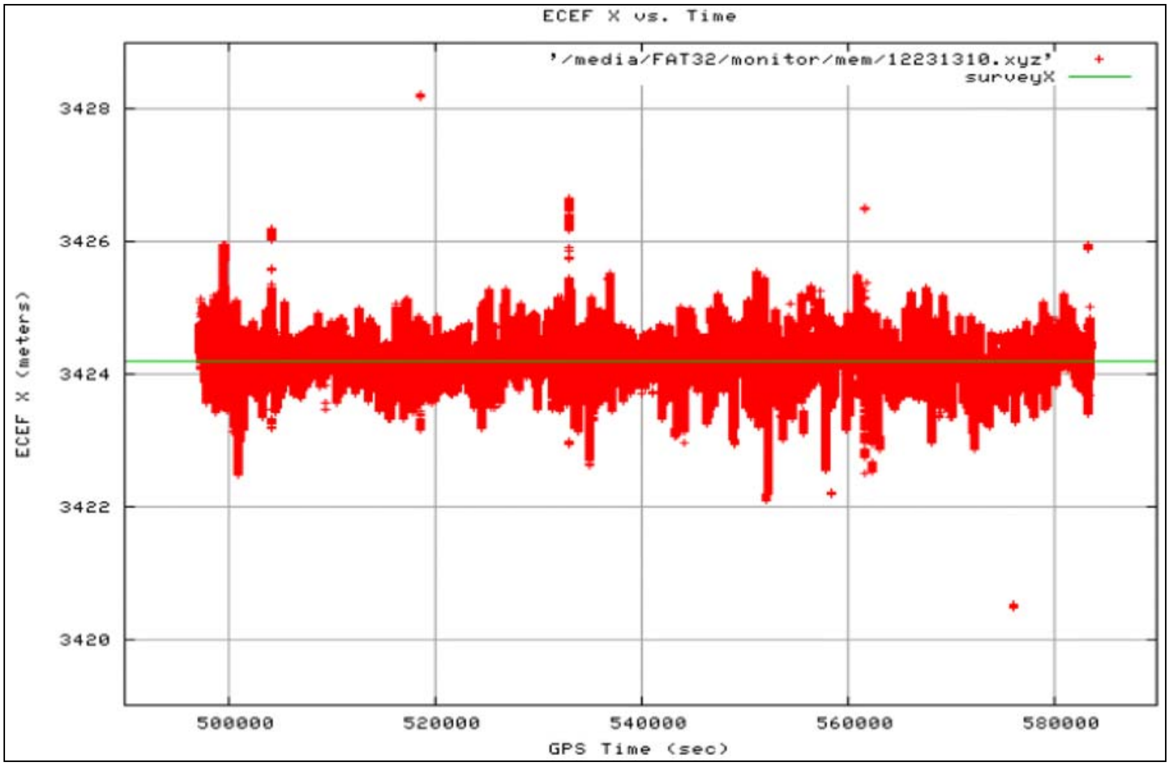


Figure 10: Memphis Raw Data Plot Example (ECEF – X vs. Survey)

5.5.2.3 Future Memphis Work / GPS Anomalous Event Monitor (GAEM)

Initial results are promising; with improved performance expected as Honeywell and the FAA move toward a provably safe LAAS system at Memphis. **Figure 11** is a screenshot example of the live web FAA position monitoring of the Honeywell Beta LAAS in Memphis. The blue traces are the calculated horizontal and vertical position error versus survey, while the red traces are the calculated horizontal and vertical protection levels (not Alert Limits). The green field in the center is the number of SVs available with corrections. Cat I performance is clearly indicated at the time this shot was generated.

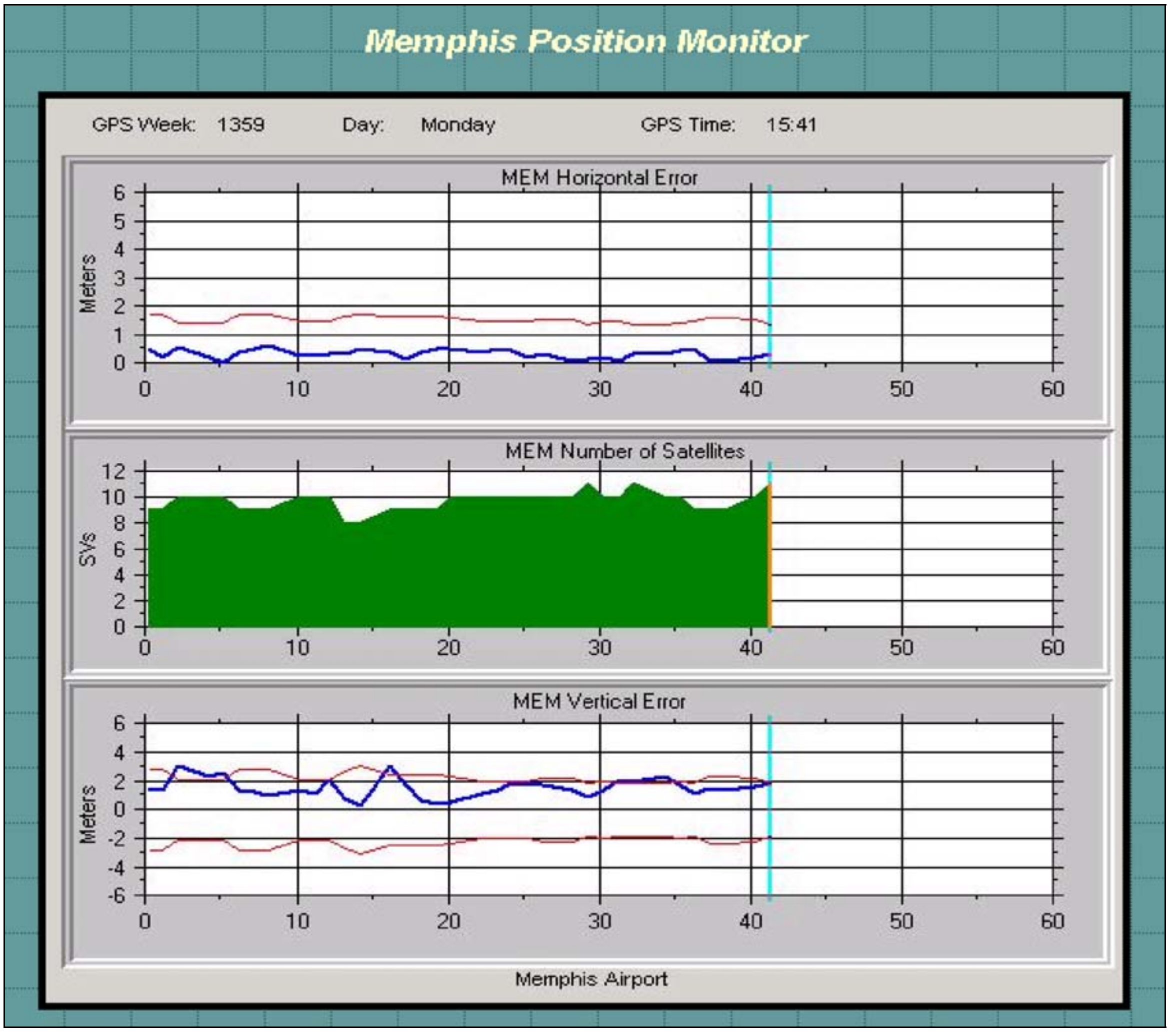


Figure 11: Memphis Position Monitor – Web Display

Supplemental performance and integrity monitoring systems are also being developed to verify the effectiveness of the Memphis Honeywell Beta LAAS system upgrades as the system approaches “provably safe integrity prototype system” status. One such system is referred to as a GPS Anomalous Event Monitor (**GAEM**). Ohio University’s Avionics Engineering Center (AEC) developed the GAEM concept, and the original prototype system. The AEC and FAA are currently in collaboration to develop the latest version of the GAEM for the FAA’s use in Memphis.

The GAEM system, although complex, is basically a stand-alone GPS RF spectrum performance monitor with enhanced GPS Signal Quality Monitoring (SQM) capabilities. When a signal anomaly is detected the entire GPS spectrum, which is continuously being digitized in RAM, is archive recorded for a ten second duration surrounding the event. This digitized spectrum data can be used to further study the anomaly at a later time. The data can also be used verify the operation of yet to be implemented integrity monitors for the Honeywell LAAS system. Later this year these integrity monitors will be active, and will need an independent method of verification. Verification will involve a comparison of Honeywell system integrity alerts versus GAEM events. This comparison will allow the FAA to judge if the Honeywell system is integrity alarming when it should and/or when it should not.

Development of the actual GAEM system to be used in Memphis began during the summer of '05 with the specification and procurement of the over 260 individual components. The first batch of technical materials was provided to the AEC during September '05, and during this reporting period development continued as FAA and AEC resources became available. Technical Center personnel visited with the AEC during the week of December 19th to see the GAEM system mock up, and for familiarization of the latest operational and user concepts.

The GAEM system for Memphis is anticipated to be available at the Technical Center by April '06, with an installation visit to follow shortly thereafter in Memphis.

5.5.3 BAE Systems DGPS Antenna (ARL-1900) Development and Testing

5.5.3.3 Background

The LAAS program has long been interested in a single feed DPGS antenna for use as a suitable sensor for the LAAS reference stations. Several types were tested over the years with no success in meeting the coverage (5° to 90°) and accuracy specification (see GAD **Section 8.6.4**) simultaneously. Meanwhile the only available antenna, that met the accuracy and coverage requirement, was a dual feed hybrid antenna (IMLA, see **Figure 5**) developed by dB Systems.

While this hybrid IMLA antenna system is excellent, and exceedingly innovative in design, it adds some complexity to the LAAS system. The hardware and software issues that are introduced by the IMLA include; additional points of possible failures (cables, components, etc.), azimuth variation/dependence due to certain design aspects, wind load limitations of certain radome types, and a continuous calculation of a dynamic "hardware bias" which is dependent on the availability of at least one common satellite being tracked on both the upper (HZA) and lower (Dipole) antennas. While the hardware bias calculation is well understood, and similar calculations would likely be required of any antenna, there are periods in CONUS constellations where the GPS coverage in the IMLA segments overlap region (25° to 40° elevation – assured by specification) drops to one satellite. The accuracy of this calculation can therefore be degraded by a single NANU (SV Outage) during these periods.

The FAA has worked with BAE Systems in the past, and was familiar with an early version of their 15-element single feed DGPS antenna array. While the early version had not quite met the accuracy and coverage specification, the designers demonstrated that they could improve the performance to meet the required specifications.

5.5.3.2 BAE Systems ARL-1900 Antenna Procurement and Testing

The FAA pursued a multi-phase contract with BAE Systems during the latter half of 2004 to develop the multi-element prototype DGPS antenna. The antenna, in addition to meeting the L1 related requirements currently in the LAAS specification, also needed to provide complete GNSS band (1164 – 1587 MHz) coverage within specified performance parameters. The BAE Systems team, under the group heading of Communications, Navigation, Identification and Reconnaissance (CNIR) in Greenlawn New York, confidently pursued the challenging antenna design task. The engineering lead on the BAE Systems team is Alfred R. Lopez.

A single element prototype antenna (see **Figure 12**) was first to be developed (Phase 1) for the FAA, and was available for validation field-testing in March 2005. Upon successful conclusion of the validation field-testing of the single array element design, the FAA pursued the completed prototype array (Phase 2). The sole existing 19-element ARL-1900 array antenna was then developed and chamber tested (L1/L2/L5/GNSS) for the FAA by Mr. Lopez's BAE team. The completed prototype was delivered to the Technical Center in December 2005 for required FAA validation field-testing.

Figure 12: BAE Single Element Antenna

The completed ARL-1900 (see **Figure 13**) array antenna was swiftly deployed to a well characterized, and precision surveyed, LAAS reference station site within the FAA's LTP #1 (LT2, see **Figure 1**). The antenna output was routed immediately to the LTP reference station L1 receiver and included as one of the four LAAS references within LTP #1. LAAS typical performance was immediately apparent by real-time observations of data available from the LAAS processing station's user platform. Post data processing (CMC see **Section 8.6.4**) techniques, however, were utilized for complete performance validation (see **Figure 14**).

Figure 13: BAE ARL-1900 (S/N #0001) as installed at LT2 12/15/05

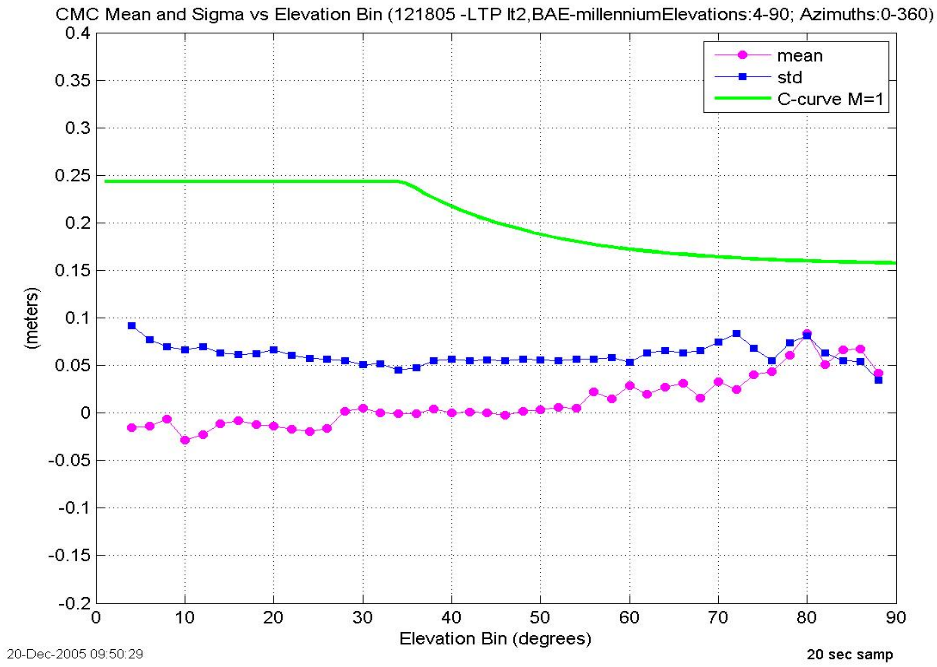


Figure 14: BAE ARL-1900 - GAD C-Curve Field Testing Performance

Additional GPS resources (other than L1 only), and accompanying post-processing techniques, are also being utilized for L2, GNSS, and survey sensor performance testing. Initial results indicated that BAE had met the specifications for L1/L2, and a complete series of further testing scenarios was in progress at the end of this reporting period.

5.5.4 LGF Software Testing and Development

The FAA, and Titan personnel are supporting a comprehensive LGF software development and update effort. The new software platform, which encompasses the operating system (OS), functional software code, and operator interface, was desired due to difficulties and shortcomings with the current platform (QNX). Lab development of a Linux based operator platform began approximately 16 months ago. Linux was chosen due to its flexibility, speed, support, economy, and similarities to Lynx. Linux provides a venue for early development, while providing a compatibility path to Lynx. Lynx is a real time OS while Linux is not. It is planned to switch over to a Lynx based operator platform as soon as funding is available, meanwhile development can continue on the freeware Linux operating system.

The new platform software incorporates functionality for all available FAA LAAS capable receiver types, while allowing for either serial or Ethernet communications for data flow. Obsolete and legacy code is being eliminated. Updated operator screens, based on LAAS team feedback, have also begun to be incorporated into the system.

Improved documentation, and software edit tracking measures are being employed and actively maintained. User-friendly flowcharts are being generated with Imagix for individual, file level, routines and definitions. Editors are required to check-in and checkout software using a newer system known as Concurrent Version System (CVS). This CVS software maintains the baseline code, and allows users to revert to previous versions. The current version of the LTP developmental ground station code is Version 3.2.

This reporting period was used for the testing and updating of two recently developed monitoring modules named the Data Quality Monitor (DQM) and Measurement Quality Monitor (MQM), which have been incorporated into the test version ground station software. The DQM consists of ten different fault tests to help determine if a particular satellite should be removed before calculating a solution. The 10 DQMs and 4 MQMs are described briefly in the following text, some of the content may be unfamiliar to those with limited knowledge of GPS data structures.

Live testing of the developmental user platform, and accompanying code, is performed by swapping out the LTP processing station CPU for the test CPU. Lab testing is also conducting during the entire development process using mock LAAS reference stations and/or replayed data. Live testing, however, must be performed periodically using the legacy, and well characterized, LTP reference stations so a direct performance comparison can be conducted. Real time and post data analysis techniques are both required for this type of effort. Live testing for this reporting period was conducted from November 18th through November 22nd, and again from December 1st through December 4th 2005.

5.5.4.1 DQM Module Content

The "Bad IODC" test checks that the lower 8 bits of the Issue of Data, Clock (IODC) in Sub-frame 1 match the Issue of Ephemeris Data (IODE) in Sub-frames 2 and 3. The "HOW bit 18 set to 1" test checks if the Handover Word (HOW) bit 18 in all 3 Sub-frames is set to "1". If any of the 3 Sub-frames has this bit set, it would result in a failure of this test. The "Data bits in Sub-frames 1, 2, or 3 set to 0" test checks the data fields in Sub-frames 1, 2, and 3. If any of them are set to all zeros, this would result in a failure of this test. The "Sub frames 1, 2, or 3 set to default" test checks the data fields in Sub-frames 1, 2, and 3. If any of them are set to default values, this would result in a failure of this test. The "Preamble Incorrect" tests the upper 8 bits of the telemetry (TLM) word (known as the Preamble). These 8 bits must be set to 8B hex in all 3 Sub-frames. If any of them were not set correctly, this would result in a failure of this test. The "Almanac Delta" test monitors the difference of the almanac position from ephemeris with a trigger value of plus or minus 7000 meters. This test actively compares ephemeris data with almanac data and if the difference is more than 7000 m, this would result in a failure of this test. The "Ephemeris CRC changes and IODE remains" test monitors the data fields in Sub-frames 1-3 have changed, then the IODE field also had to have been changed. If not, this would result in a failure of this test. The "GPS PRN = 33-37" test checks if the PRN for the ephemeris message is set to a value of 33-37 (reserved PRN values). If it does, this would result in a failure of this test. The "Satellite Declared Unhealthy" test monitors the satellite health field in Sub-frame 1 and is a 6-bit field. The MSB is a summary of the health of the NAV data and if this bit is set to 1, some or all of the NAV data is bad and would result in a failure of this test. The "Consecutive Ephemeris Delta" test monitors if consecutive ephemeredes differs by more than 250 meters, if the difference is more than 250 m, this would result in a failure of this test.

A summary listing of all of the DQM fault tests are as follows, (as specified in FAA-E-2937A);

1. GPS PRN 33-37
2. Satellite Health
3. Preamble
4. HOW Bit 18
5. Bad IODC
6. Subframes set to 0
7. Subframes set to default
8. Ephemeris CRC changes and IODE does not
9. Almanac to Ephemeris
10. Ephemeris to Ephemeris

5.5.4.2 MQM Module Content

The MQM module currently consists of four different fault tests to help determine if a particular satellite should be removed before calculating a solution. The "Low Power" test monitors acceptable levels of carrier noise for SV elevations from 0-90 degrees using a bottom floor number adding in corrections for satellite gain and atmospheric adjustments. The Carrier Noise Ratio (CNO) is compared to these values and if the CNO falls below the acceptable level at any elevation, it would result in a failure of this test. The "Code Carrier Divergence" test monitors values of the Code and the Carrier are compare and if they differ by more than an allowable amount, if so this would result in a failure of this test. The "Excessive Acceleration" test takes three consecutive readings of the reported pseudorange. The difference of the first two is subtracted from the difference of the 2nd and 3rd measurements and if they differ by more than an allowable amount, this would result in a failure of this test. The "Innovation" test is designed to monitor for step increases in the code phase. This test uses carrier phase and smoothed code phase by taking the previous smoothed code-phase plus the difference in the current and previous carrier phase and subtracting that total from the current raw pseudorange. In this way any large increases due to satellite or reference receiver are quickly observed.

A summary listing of all of the MQM fault tests are as follows, (as specified in FAA-E-2937A);

1. Low Power
2. Code Carrier Divergence
3. Excessive Acceleration
4. Innovation

5.5.4.3 Future Software Development Activities

Lab and live testing of the developmental user platform provides valuable data that is used to identify any possible problem areas, and ultimately requirement(s) satisfaction. When a problem area is identified it is revisited for required updates.

The future version of the LTP integrity monitor will include a test for ephemeris Type B failure. This test will verify that newly updated ephemeris data is consistent with previous ephemeris, sometime referred to as yesterday's ephemeris to today's ephemeris, or the "YE-TE" test. An updated method of the Excessive Acceleration MQM is to be developed utilizing Pseudorange data. A refined dynamic Clock Error correction method is also being developed for the MQM.

6 LTP Maintenance and Updates

The FAA's LTP requires little maintenance. The system's components do falter on infrequent occasions and require replacement. More common is the need to retrieve the raw archive data, which entails the swapping out an empty external hard-drive.

The LTP is an AOA-installed operational LAAS system and requires the same type of airport maintenance activities required for other AOA-installed systems.

6.5 Routine Maintenance

External hard-drives for raw data collection are switched on a weekly basis, but could go as long as 45 days without this operation. This operation requires an interruption of service due to the hardware limitations inherent to the real time operating system. An interruption of approximately seven minutes is required to perform this operation.

6.6 Upgrades and Updates

6.6.1 Software Updates

6.6.1.1 Terminal Area Path and Procedures (TAP) Development

The LAAS T&E software team modified the existing LTP (Heliport System) software to transmit TAP data for two runways at Atlantic City International Airport. TAP data for R/W 13 and R/W 4 was imported into the LTP database and tested using a Rockwell

Collins MMR. New Runway Path Data Selector (RPDS) numbers were assigned to these approaches so that the pilot could “tune” in the approach. Now, because of the unlinked TAP procedures, the ground system closely resembles the new version of the MOPS (DO-246C). Flight tests were conducted at ACY with astonishing results.

TAP information greatly improves the National Airspace System (NAS), by allowing the ATC/Pilot to utilize waypoints for an approach, which may or may not consist of a curved approach procedure.

Figure 15 is an “approach plate” from which the runway 13 curved approach is derived. Used as a pictorial representation of the approach, an approach plate it utilized by air traffic control and pilots for “at a glance” identification and familiarization of a given procedure, automated or otherwise.

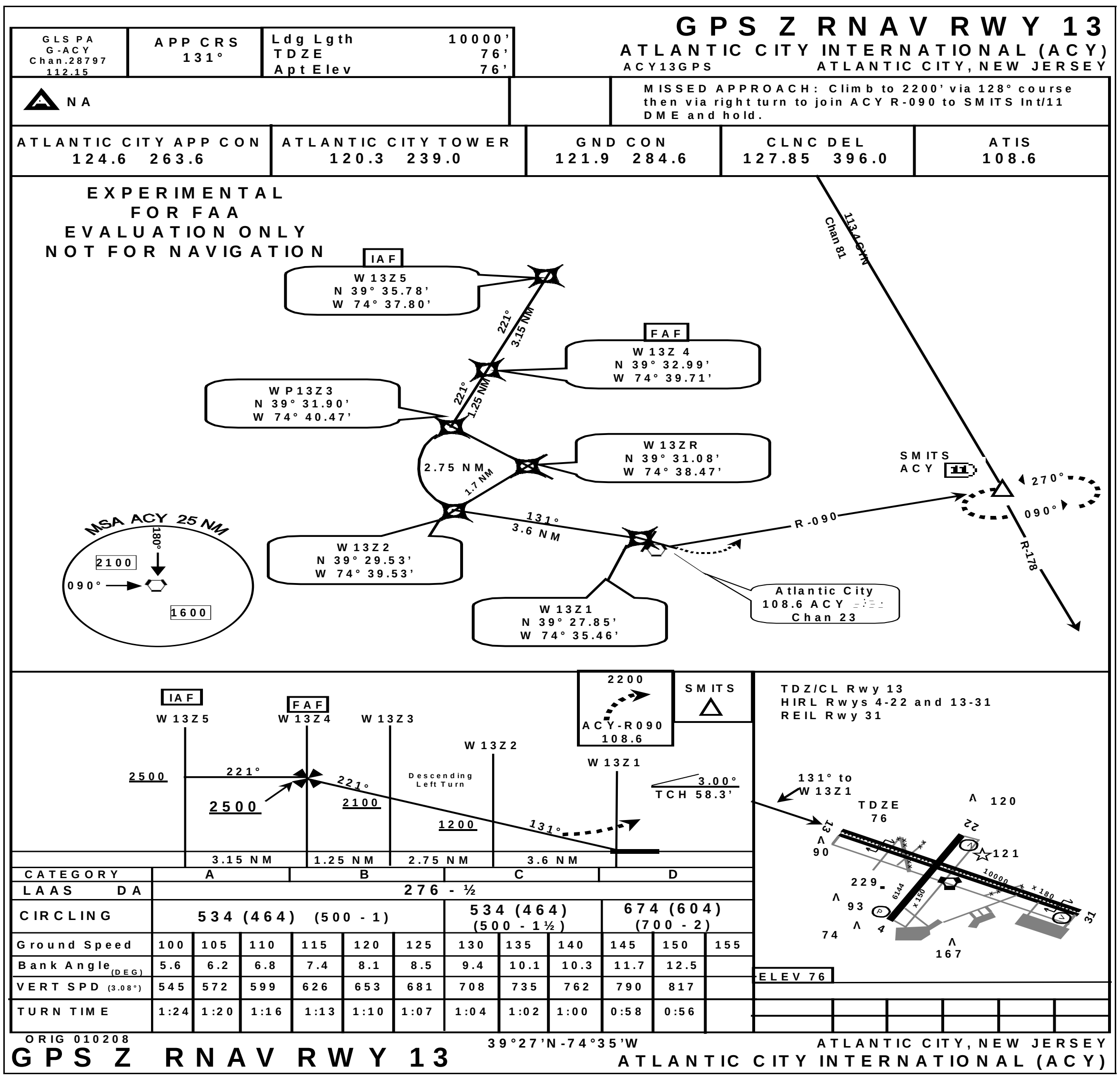


Figure 15: Approach Plate of ACY Runway 13 Curved LAAS Procedure

6.6.1.2 Hardware

No long-term updates (testing related updates only) were done on the ground or air systems during this reporting period.

6.7 Failures and Forced Events

This section highlights failure modes experienced during the reporting period. Being a prototype system, the LTP doesn't employ all the backups and protections that would be incorporated into a fully compliant Category I LAAS. The LTP also utilizes some consumer grade hardware, which can contribute to certain failure modes.

A Technical Center wide power outage forced the complete shutdown of the LTP, and monitoring systems from October 7th through October 11th.

7 Significant Weather and Other Environmental Events

This section is reserved to highlight any environmental events that drove system performance to inflated or unacceptable levels or caused a system outage. Events of this type are rare but could include: solar flares, ionosphere storms, geomagnetic disturbances, and limited catastrophic weather events.

8 LAAS Performance and Performance Type (Category)

The GPS Standard Positioning Service (SPS), while accurate, is subject to error sources that degrade its positioning performance. These errors sources include ground bounce multi-path, ionospheric delay, and atmospheric (white) noise among others. The SPS is therefore insufficient to provide the required accuracy, integrity, continuity, and availability demands of precision approach and landing navigation. A differentially corrected positioning service, with short baselines to the user(s), is suitable to provide precision guidance.

The relatively short baselines between the user and the LAAS reference stations, and custom hardware and software, is what sets LAAS apart form WAAS. Special LAAS hardware such as the IMLA serves to mitigate the multi-path problems, while the LAAS software monitors and corrects for the majority of the remaining errors providing the local user a precision position solution.

The LAAS Ground Facility (LGF) is required to monitor and transmit data for the calculation of protection parameters to the user. The LAAS specification also requires monitoring to mitigate Misleading Information (MI) that can be utilized in the position solution. These requirements allow the LAAS to meet the accuracy, integrity, availability, and continuity required for precision approach and landing navigation.

There are three Performance Types (PT) defined within the LAAS Minimum Aviation System Performance Standards (MASPS). The three performance types, also known as Categories, (Cat I, and Cat II/III) all have the same parameters but with different quantity constraints. For the purposes of this report, the LTP assumes Cat I Alert Limits and hardware classification.

8.6 Parameters and Related Requirements Overview

This section highlights the key parameters and related requirements used to depict LAAS system performance in this report. In order to provide the reader a clearer understanding of the plots provided, a little background is useful.

Cat I precision approach requirements for LAAS are often expressed in terms of Accuracy, Integrity, Availability, and Continuity. For clarity the use of these four terms, in the context of basic navigation, are briefly described below:

- **Accuracy -** is used to describe the correctness of the user position estimate that is being utilized.

- **Integrity –** is the ability of the system to generate a timely warning when system usage should be terminated.

- **Availability** - is used to describe the user's ability to access the system with the defined Accuracy and Integrity.

- **Continuity** - is used to describe the probability that an approach procedure can be conducted, start to finish, without interruption.

Parameters used to depict LAAS performance in the remainder of this report are outlined below:

8.6.1 VPL and LPL

Accuracy for a Cat I LAAS is best quantified in terms of the vertical and lateral (horizontal) Navigation Sensor Error (NSE). LAAS position is translated into vertical and lateral components of error with respect to the pre-defined path in space. The 95% limits for lateral and vertical NSE defined in the LAAS MASPS are used as a performance measure. The 95% Vertical NSE limit tightens as the user descends toward the Runway Datum Point (RDP) on the final approach path. For heights above the RDP of 1290 ft or more, the Vertical NSE limit is 16.7 meters. For heights between 1290 and 200 feet the vertical NSE limit begins at 16.7 meters (at 1290 feet) and traces a straight line down to 4 meters (at 200 feet). This 4-meter Vertical NSE limit is maintained to 100 feet above RDP along the final approach path. The 95% Lateral NSE limit is similar in construct, but is related to horizontal distance from the RDP along the final approach path. For distances beyond 7212 meters the Lateral NSE limit is 27.2 meters. For distances between 7212 and 873 meters the Lateral NSE Limit begins at 27.2 meters (at 7212 meters) and traces a straight line to 16 meters (at 873 meters). This 16-meter Lateral NSE Limit is maintained to 291 meters from the RDP along the final approach path. Vertical/Lateral NSE and Vertical/Lateral Protection Levels (VPL and LPL) are closely related. The user's Vertical/Lateral NSE can only be determined through post processing with a precision truth tracking system. The FAA has processed hundreds of actual LAAS approaches, and monitoring station data sets, to verify the 95% Vertical/Lateral NSE of LAAS. The 95% NSEs obtained must be bounded by the user's computed VPL and LPL (a.k.a., HPL). These Protection Levels are in turn bounded by the corresponding Alert Limits. It has been shown that the NSE performance is easily within the MASPS requirements, and the need for splaying is a benefit only when it comes to the integrity bound that must be computed based on a real-time estimate of the user's position.

Integrity for LAAS is associated with known failure modes within the system and the monitors that are designed to detect the failures before it is manifested in the airborne receiver as Misleading Information (MI). Each failure mode has an associated monitor that is assigned a corresponding probability of the failure occurring, or a prior probability, and an associated probability that the failure is detected, or a missed detection probability. The Cat I LAAS Specification states "the probability that the LGF transmits Misleading Information (MI)…shall not exceed 1.5X10^(-7) during any 150-second approach interval". The LAAS MASPS defines MI as a Navigation System Error, which exceeds the Vertical or Lateral Alert Limits (VAL or LAL) without annunciation within the time to alert (3 seconds). The VAL and LAL are fixed at 10 and 40 meters (radius) respectively. These limits are not to be exceeded by the user's calculated Vertical and Lateral Protection Levels (VPL and LPL) bounds. The VPL and LPL are upper confidence bounds on the positioning error with specified probabilities. The NSE is bounded by the Protection Levels, which are in turn compared to the Alert Limits. If the user's Protection Levels exceed the Alert Limits the approach is flagged within the time to alert of 6 seconds. There are actually a number of parallel hypotheses (see LAAS MASPS) used in determining the user's Protection Levels. The VPLmax and LPLmax (worst case) calculation is the level that is applied for comparison to the alert limits. In basic terms, the relation is as follows:

Vertical NSE < VPLmax < VAL = 10 meters
Lateral NSE < LPLmax < LAL = 40 meters

Continuity and ***Availability*** are related, but are not interchangeable. A system must first be available before you can determine if it meets continuity. LAAS could be available at the initiation of the approach, but an unfavorable constellation change or other event could make the approach unavailable before it is completed. Therefore, this approach would suffer a loss of continuity. For the purposes of this report Availability and Continuity are analyzed in terms of LAAS Protection Levels that are within the alert limits for a given time period (24 hours). The LAAS MASPS states, for Cat I, that "the overall probability of a loss Continuity due to a Protection Level exceeding the Alert Limit shall not exceed 7.8X10^(-6) per 15 seconds". A properly configured and maintained LAAS, such as the FAA's LTP, can meet this constraint without any difficulty. The 24-hour VPL/HPL plots provided in this report are most stable and repeatable, and in fact appear identical from one day to the next. Long and short-term system Availability is difficult to quantify for a prototype system such as the LTP, and is accordingly out of the scope of this report. Section 6, most notably section 6.3, is intended to provide the reader a glimpse at the events that effect the Availability of the LTP system.

8.6.2 VDOP and HDOP

Vertical and Horizontal Dilution of Precision (VDOP and HDOP) parameters of the SPS is actively monitored since the LAAS is required to perform with a worse case constellation and geometry. VDOP/HDOP parameters are directly tied to constellation geometry, and when combined with pseudorange errors affect the SPS position estimate and time bias. Diverse constellation geometry will provide less dilution, while confined constellation geometry will drive dilution higher. What is ultimately diluted is the user's uncorrected Vertical and Horizontal position estimate. Monitoring the VDOP and HDOP in the LAAS ground station gives a valid picture of what the user is experiencing and provides a quantity to the DOP components of error that is experienced prior to applying to a differential correction.

8.6.3 Clock Error

The average Clock Error is important to monitor since rapid changes in the ionosphere can drive the clock error to unusual levels. For the purposes of this report the clock error is presented solely to present a history of a typical clock error condition on a typical day. Clock error will invariably rise when the Total Electron Count (TEC) of the ionosphere is high (day), and fall when the TEC is lower (night). The derived average system clock error is correctable and in general amounts to between 5 and 15 meters (between 0.166 and 0.550 nano-seconds). Much larger clock biases are tolerable as well. The reference receiver clock biases are largely removed from the pseudorange correction (PRC) before these corrections are sent to the airborne equipment. Each PRC measurement could contain a residual clock error that is not removed. The residual clock error is relatively small and complicated to accurately measure. Therefore an estimate of the PRC error (referred to as a B-Value) is calculated elsewhere in the system and is software monitored to actively exclude any single measurement(s) that exceeds a given threshold. Deviations from the cyclical and roughly sinusoidal shape and magnitude of the graph will likely indicate a disturbance that will prompt further investigating to see if other parameters were adversely affected.

8.6.4 Code-Minus Carrier (CMC) and Reference Segment Status

(**CMC**)[2] values are computed for each SV on each antenna segment (eight total, two per reference). The initial CMC quantity is computed by converting the L1 Carrier phase into a range and subtracting it from the Code range (also known as the pseudorange). Additional processing is required to isolate the code Multipath and noise components, which include subtraction of the sample-mean to remove the carrier phase integer ambiguity. Further computation is required for the removal of the ionospheric delay. The ionospheric delay is computed from the L1/L2 carrier phase measurements obtained from the L1/L2 IONO station (see Section 5.4).

The CMC values have had the effect of ionospheric delay (as determined from the L1/L2 IONO antenna data) removed from it, and has been smoothed. The CMC value can therefore be considered error that is uncorrectable, and uncommon to the ground station

[2] CMC – For in-depth explanation on this method refer to ION Navigation Journal, Winter 94/95, volume 41, Number 4, page 415, "Isolation of GPS Multipath and Receiver Tracking Errors" (Braasch).

and airborne user. This uncorrectable error consists primarily of Multipath, noise, and hardware biases. The error is minimized by custom LAAS hardware design and adherence to the LAAS siting requirements.

Due to the configuration and siting of the reference stations of the LTP the typical antenna segment error reported has a standard deviation trace residing in the 0.05-meter region. The CMC values and statistic plots are continually monitored to unsure minimum obtainable levels are maintained.

In order to observe overall system performance, the CMC, **number of samples (NOS)**, and **carrier-to-noise** (**C/No**) ratio values from all four reference stations' dipole segments and HZA segments are averaged together so as to create only two sets of data (dipole and HZA) for all SVs, from the original eight antenna segments. C/No is critical to optimum reference receiver (RR) performance, and is closely monitored. The C/No is a density ratio, with units in dB-Hz, and is driven by the amount of total signal power that is permitted to enter two RF inputs of the RR. The LAAS T&E team maintains proper total input power through external attenuation the value of which is obtained by performing an AGC calibration. The NOS also serves as a representation RR performance and health. System level NOS for a given elevation bin is reasonably repeatable for a given GPS constellation. Marked changes in the NOS, without a constellation change, would prompt the LAAS T&E team to investigate and address the potential cause.

Depicted in this section are four ensemble (all data averaged and overlaid) plots that are generated using the data from all SVs over a 24-hour period. Carrier-to-noise versus time and elevation and CMC versus time and elevation, are made up of individual traces for each satellite overlaid atop one another. Also depicted are two statistics plots—mean and standard deviation of the CMC versus elevation bin and number of samples versus elevation bin, combine the data from all available SVs based on their elevation at the time the sample was recorded. For the dipole segment, data is broken into 2-degree bins from 4 to 40 degrees, for the HZA, from 25 to 90 degrees.

The standard deviation of the CMC estimate of pseudorange error is compared to the Ground Accuracy Designator (**GAD**) **"C"- curve**. Any exceedance of the GAD C-curve at the specification required elevations (5 to 40 for dipole, 40 to 90 for HZA, as applied in the LTP) is considered a performance deficiency. These deficiencies are repeatable and will not improve/degrade without human/environmental intervention. This is when the LAAS team inspects RR/RRA environment and hardware to address the problem.

There are two CMC and antenna segment status sections presented in this report for each month of the reporting period. The first is the dipole antenna section, followed by the HZA antenna section. The CMC process that the LAAS T&E team has developed generates multiple system average plots, which include: CMC error, receiver status, and statistics plots, which are presented together in the CMC sections.

The plot of CMC error magnitude versus azimuth/elevation value shows the performance of each satellite individually, with points on the plot color-coded to the maximum CMC value observed at a given azimuth/elevation pair. Referred to as the "**Average Error Characterization Plot**" these figures reveal much about the Multipath environment, and error a SV signal experiences on its path to the receiving element. Any increase in the average reported error indicates a possible problem with the system or environment, which would prompt immediate investigation by the LAAS T&E team.

8.7 Performance Analysis Reporting Method

For a given configuration the LTP's 24-hour data sets repeat performance, with little variation, over finite periods. The LAAS T&E team can make that statement due to the continual processing of raw LTP data, and volume of legacy data that has been analyzed from the LTP by the FAA and academia. Constellation and environmental monitoring, in addition to active performance monitoring tools such as the web and lab resources provide the LAAS T&E team cues for closer investigation in the presence, or suspicion, of uncharacteristic performance.

Data sets from the LTP ground and monitoring stations are retrieved on a weekly basis and are processed immediately. A representative data-day can then be drawn from the week of data to be formally processed. The resultant performance plots could then serve as a snapshot of the LTP's performance for the given week. These weekly plots are afterward compared to adjacent weeks to select a monthly representative set of plots.

8.8 Performance Summary

This reporting period witnessed stable acceptable overall system performance well within Category I limits. The performance plots depicted typify historical performance for the current LTP configuration.

No NANUs are highlighted in section 4.3. SV outages experienced for this reporting period caused no interruptions of service, or rise in key values.

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8.9 Performance Plots and Plot Organization

This report provides the reader a LTP system level performance snapshot. For narratives on the utilized parameters refer to Section 8.6 In the interest of space a representative set of plots is chosen on a monthly basis. These monthly plots are presented in the remainder of this section.

The content and organization of the LTP system performance plots, contained in the remainder of this report, are outlined below.

Reporting Period Month and Year

1) **VPL versus Time**
2) **HPL (LPL) versus Time**
3) **VDOP and Number of SV Observations versus Time**
4) **HDOP and Number of SV Observations versus Time**
5) **Clock Error versus Time**
6) **Dipole Status and CMC (System Average) (multiple)**
    - **System Dipole CMC Standard Deviation and Mean versus Elevation**
    - **System Dipole Error Characterization versus Azimuth and Elevation**
    - **System Dipole Number of Samples versus Elevation**
    - **System Dipole CMC versus Elevation**
    - **System Dipole CMC versus Time**
    - **System Dipole Carrier to Noise versus Elevation**
    - **System Dipole Carrier to Noise versus Time**
7) **HZA Status and CMC (System Average) (multiple)**
    - **System HZA CMC Standard Deviation and Mean versus Elevation**
    - **System HZA Error Characterization versus Azimuth and Elevation**
    - **System HZA Number of Samples versus Elevation**
    - **System HZA CMC versus Elevation**
    - **System HZA CMC versus Time**
    - **System HZA Carrier to Noise versus Elevation**
    - **System HZA Carrier to Noise versus Time**

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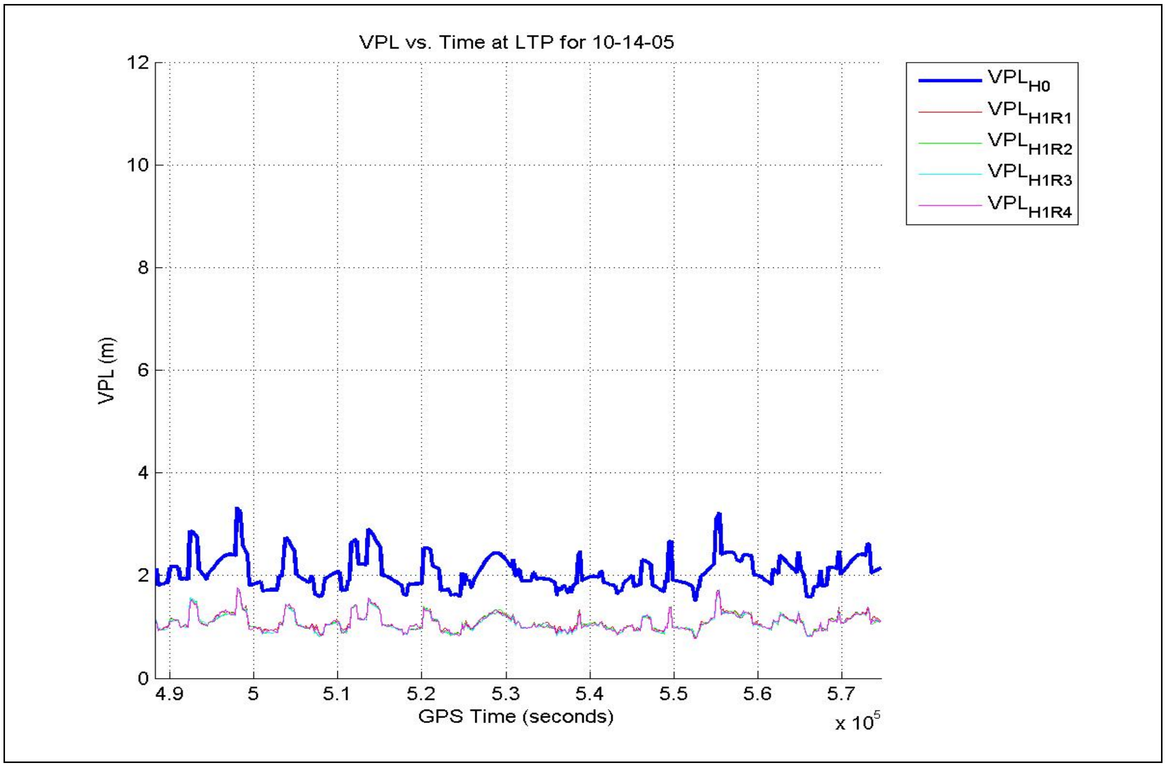
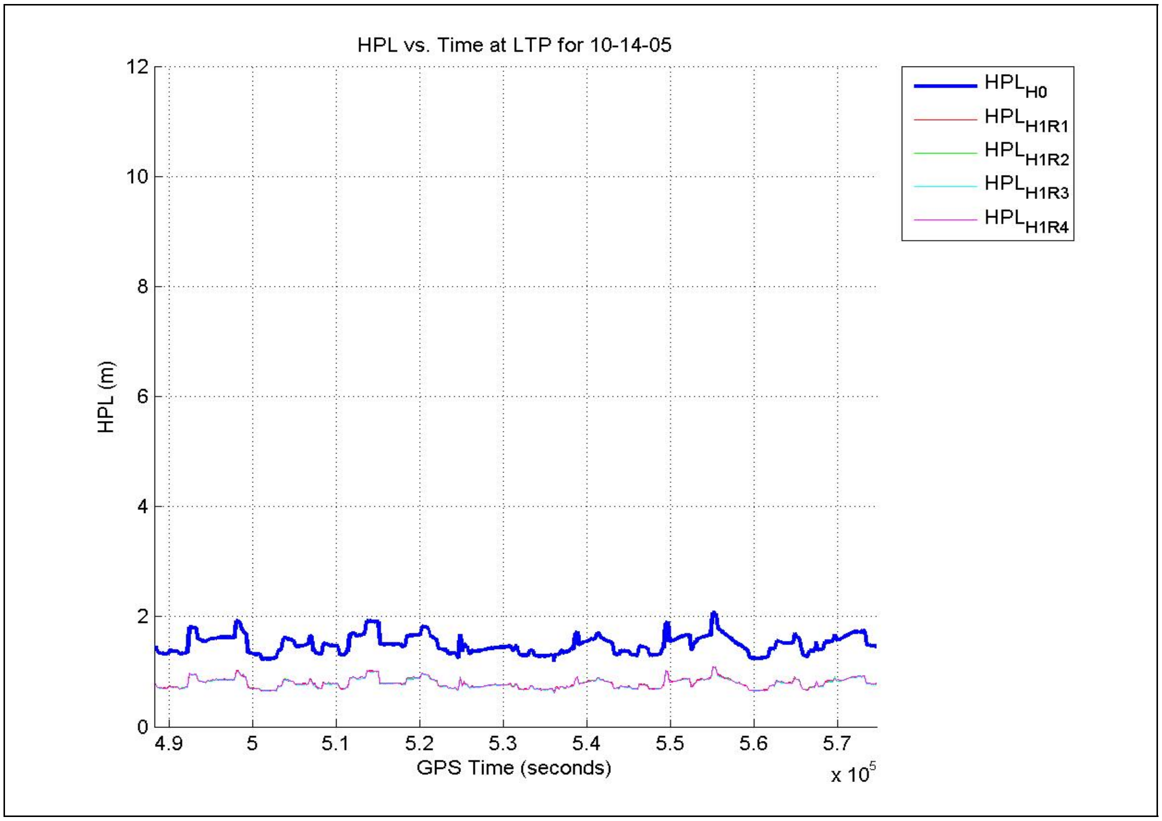
8.9.1 October 2005 Performance Plots

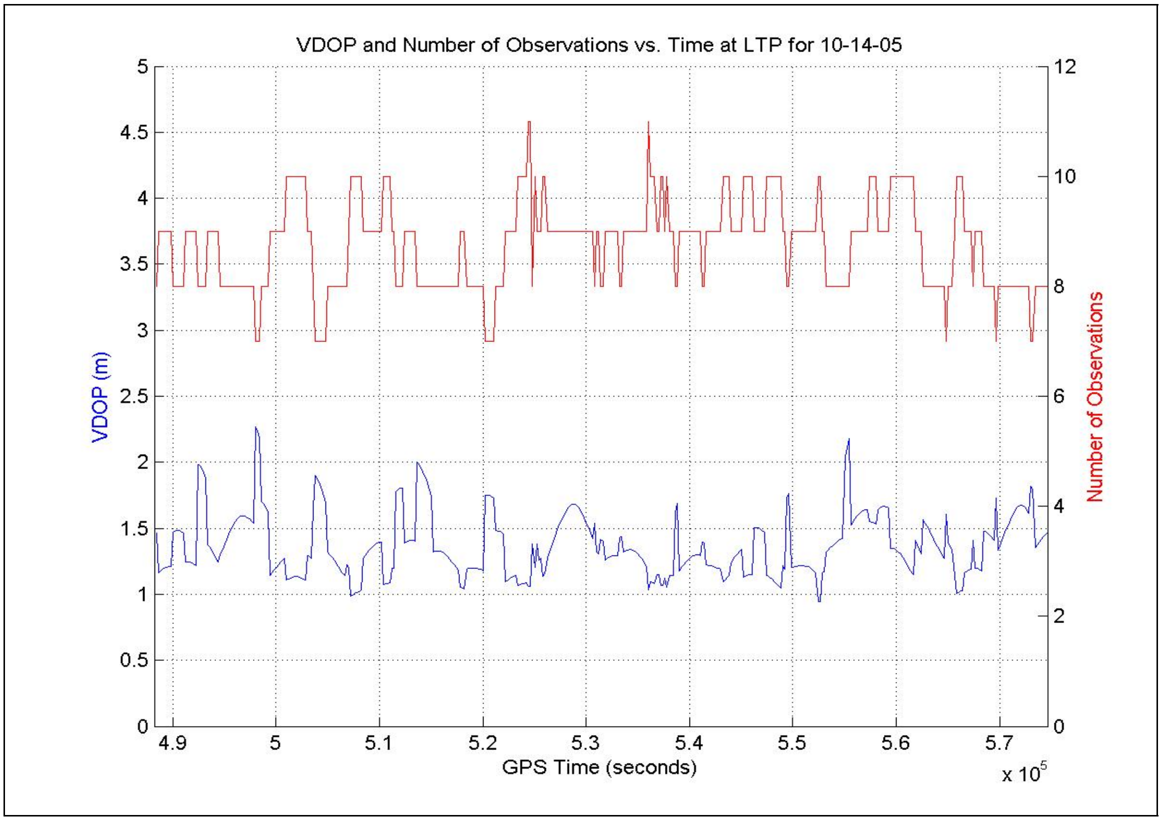
8.9.1.1 October VPL versus Time



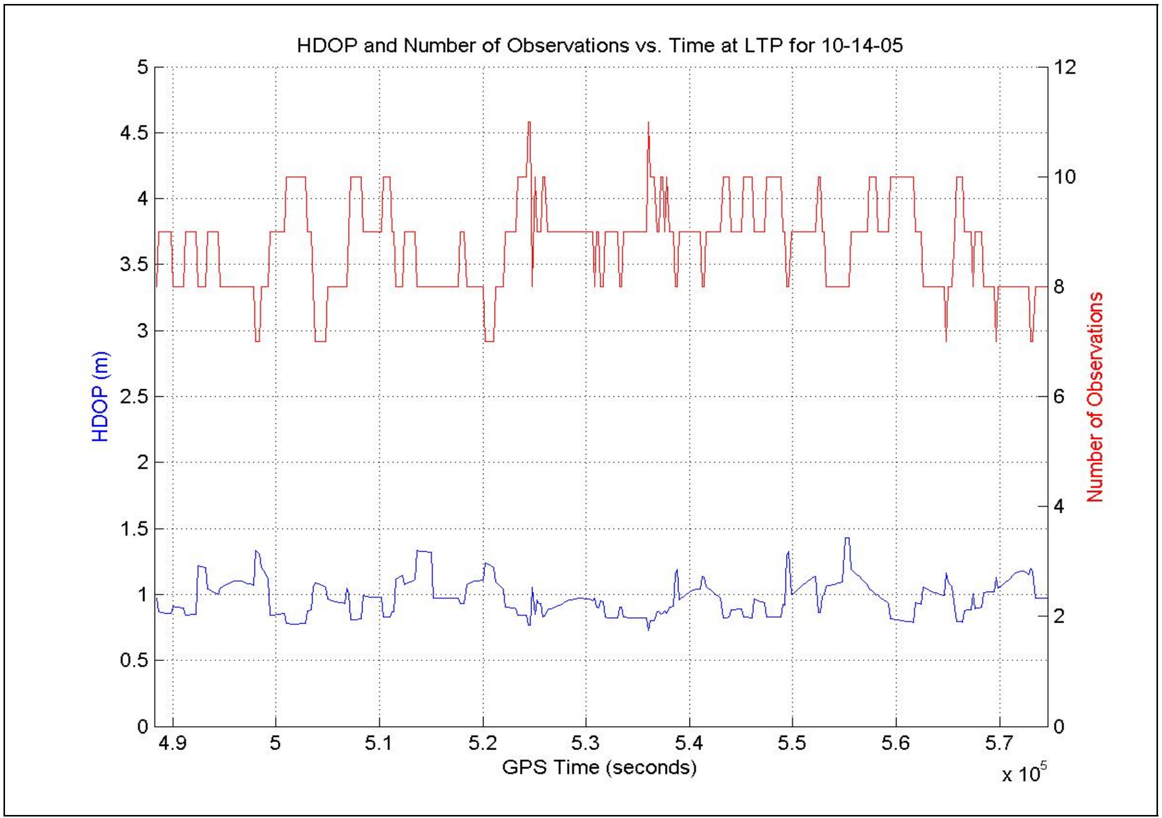
8.9.1.2 October HPL versus Time



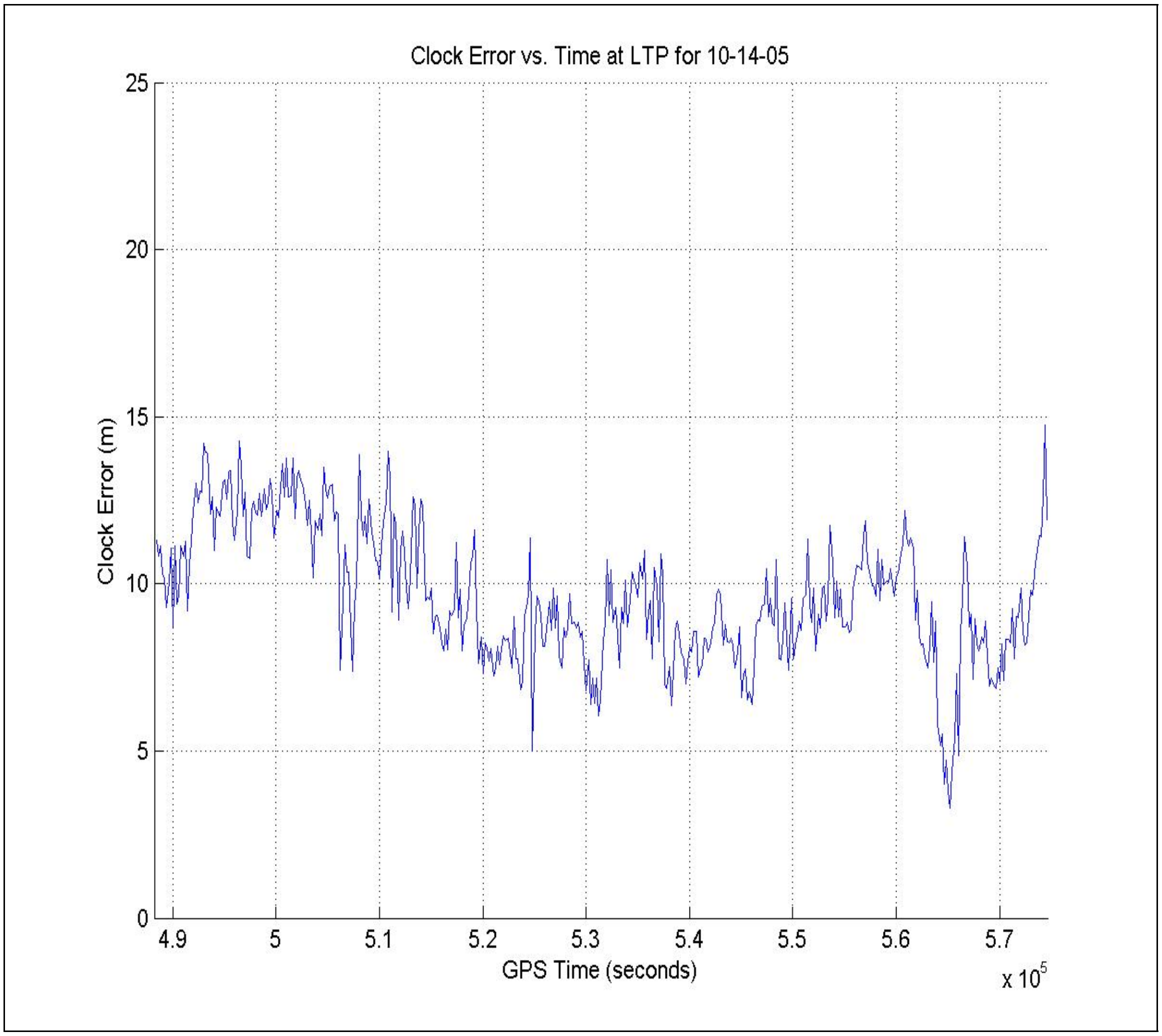
8.9.1.3 October VDOP and # of SV Observations versus Time



8.9.1.4 October HDOP and # of SV Observations versus Time

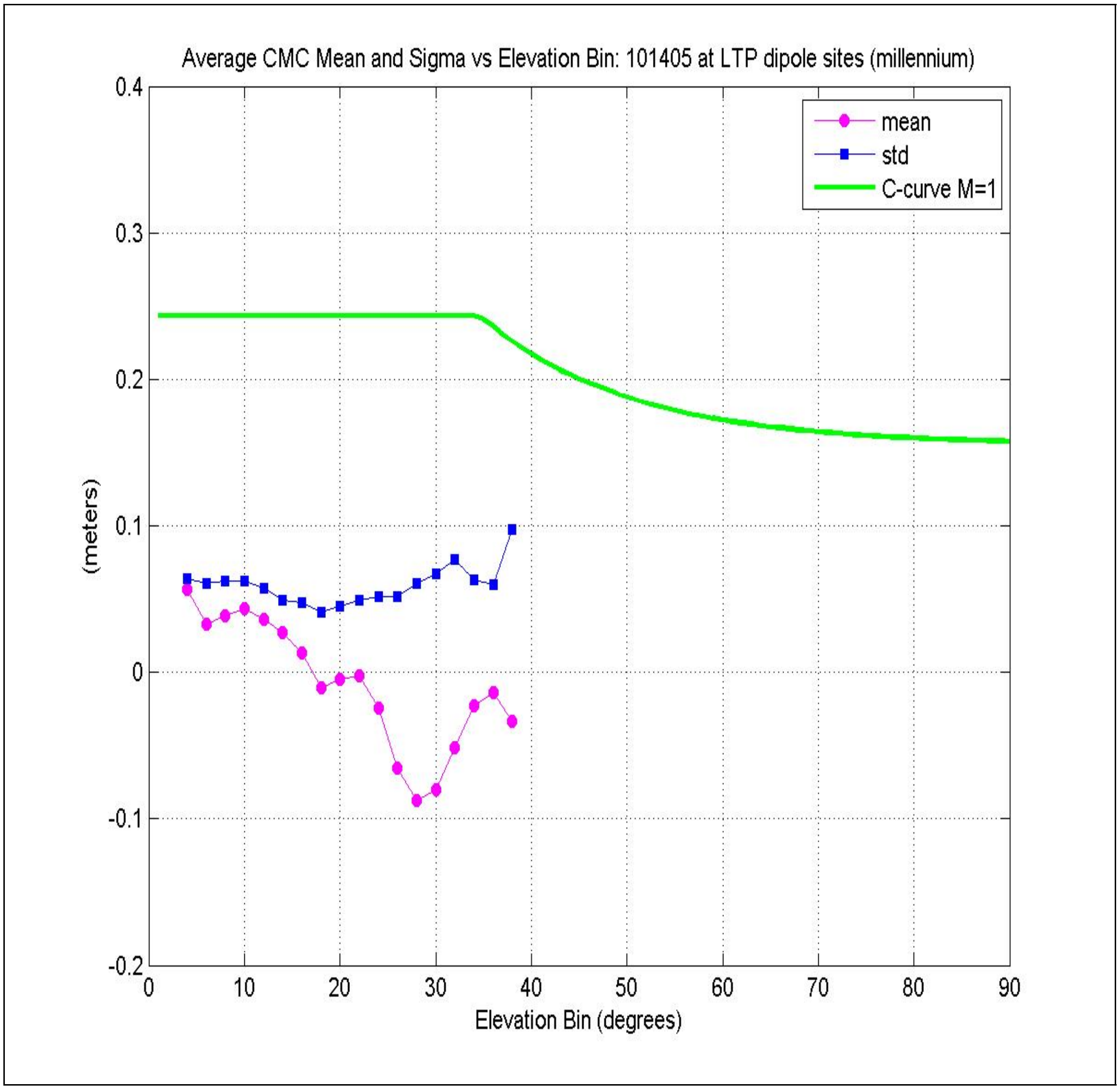


8.9.1.5 October Clock Error versus Time

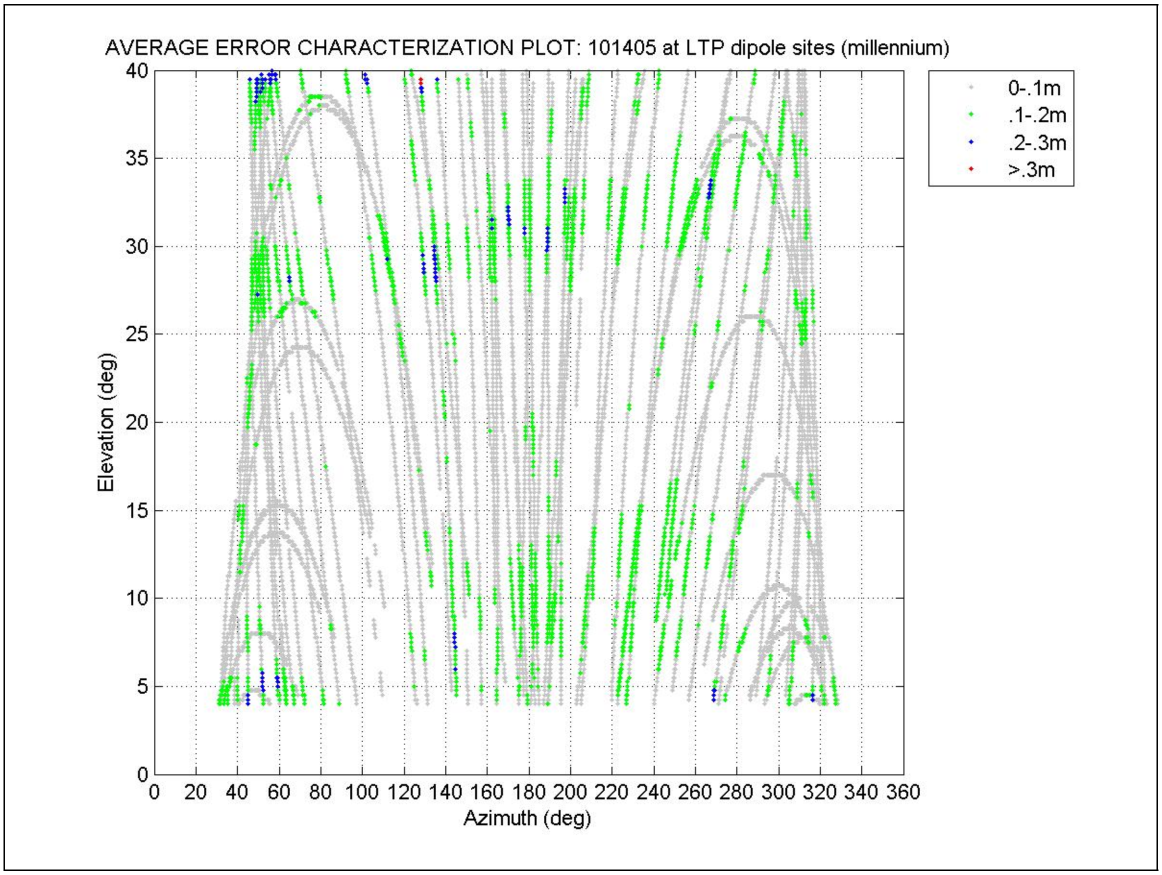


8.9.1.6 October Dipole Status and CMC (System Average) (multiple)

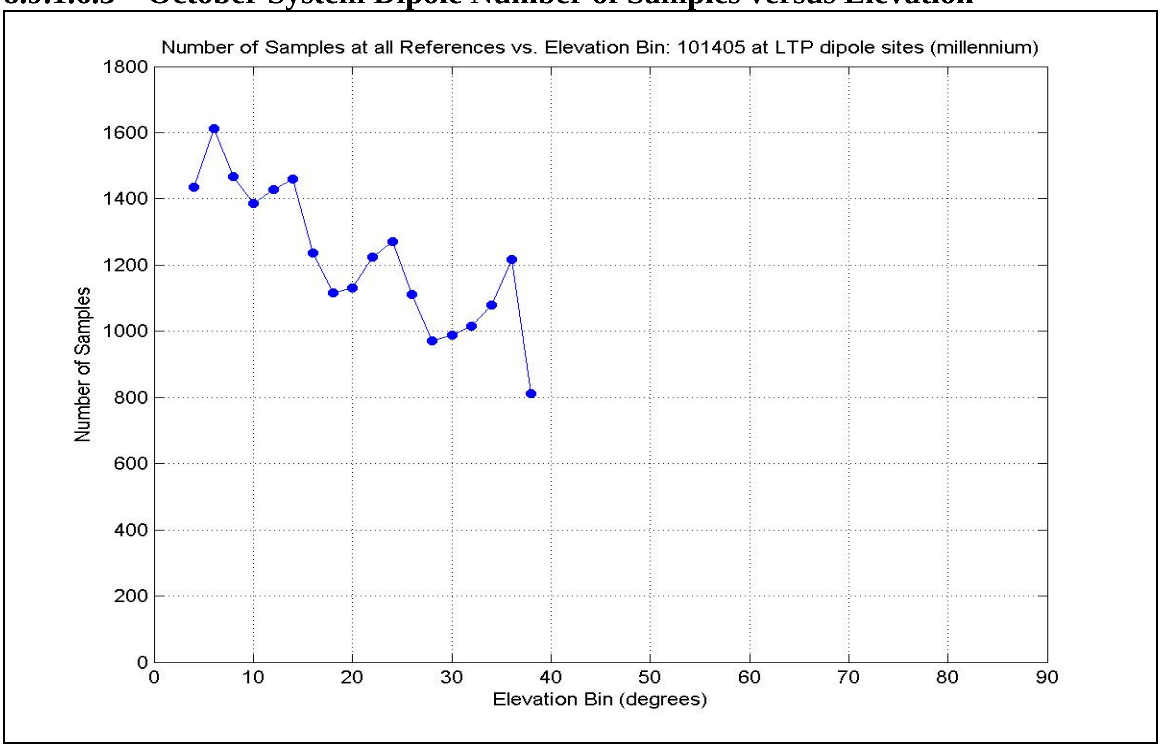
8.9.1.6.1 October System Dipole CMC Standard Deviation and Mean versus Elevation



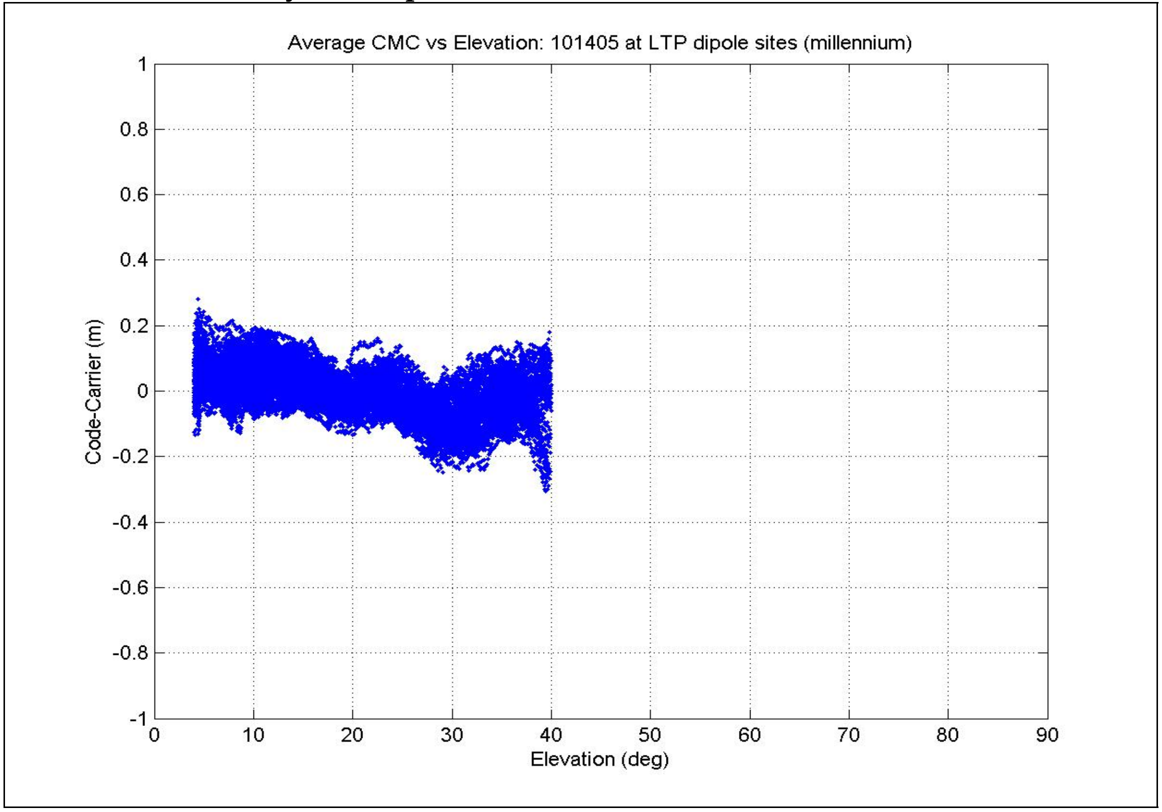
8.9.1.6.2 October System Dipole Error Characterization versus Azimuth and Elevation



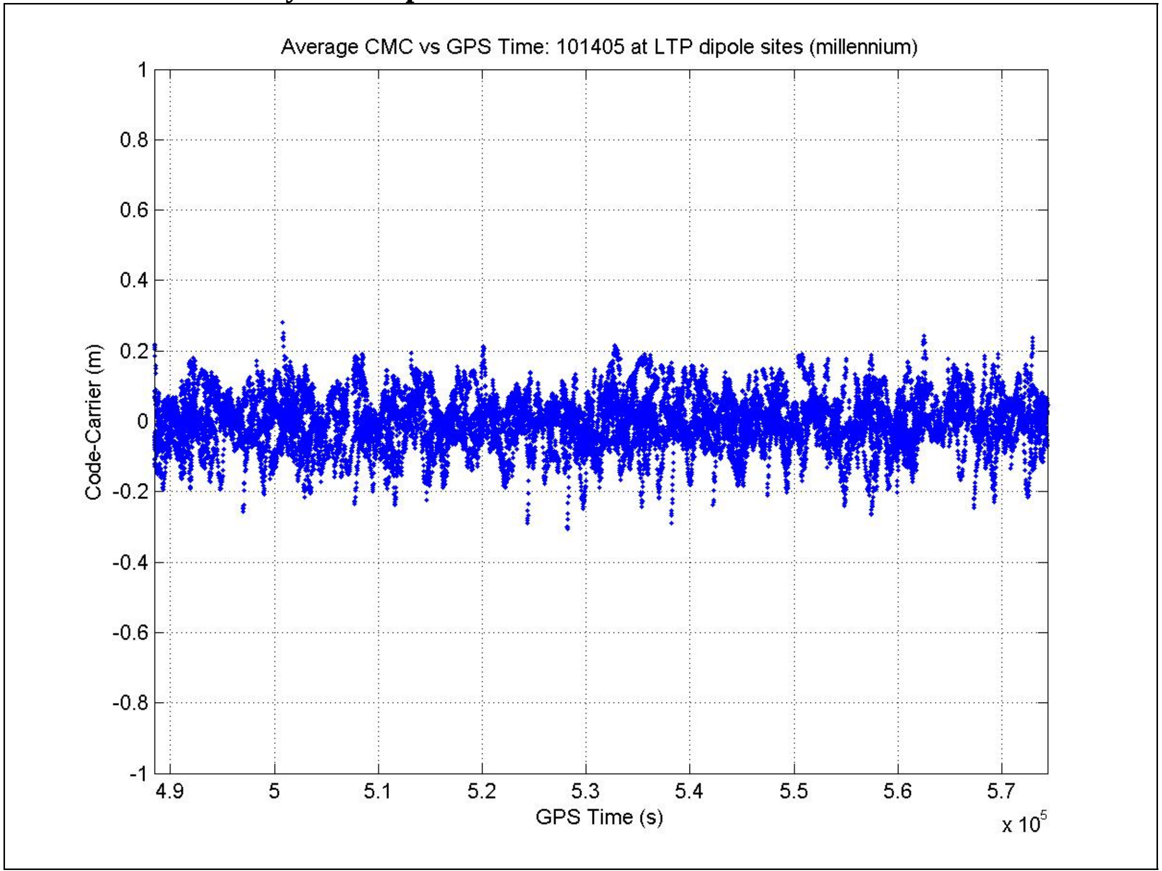
8.9.1.6.3 October System Dipole Number of Samples versus Elevation



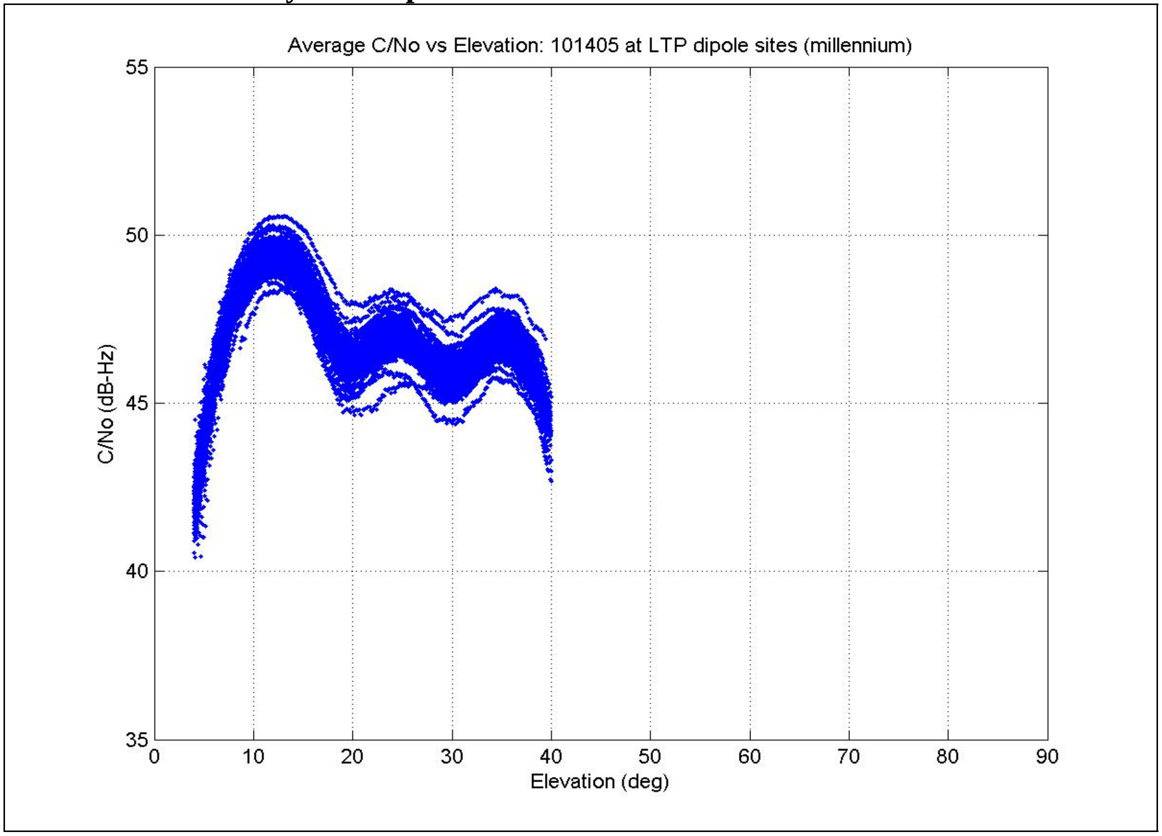
8.9.1.6.4 October System Dipole CMC versus Elevation



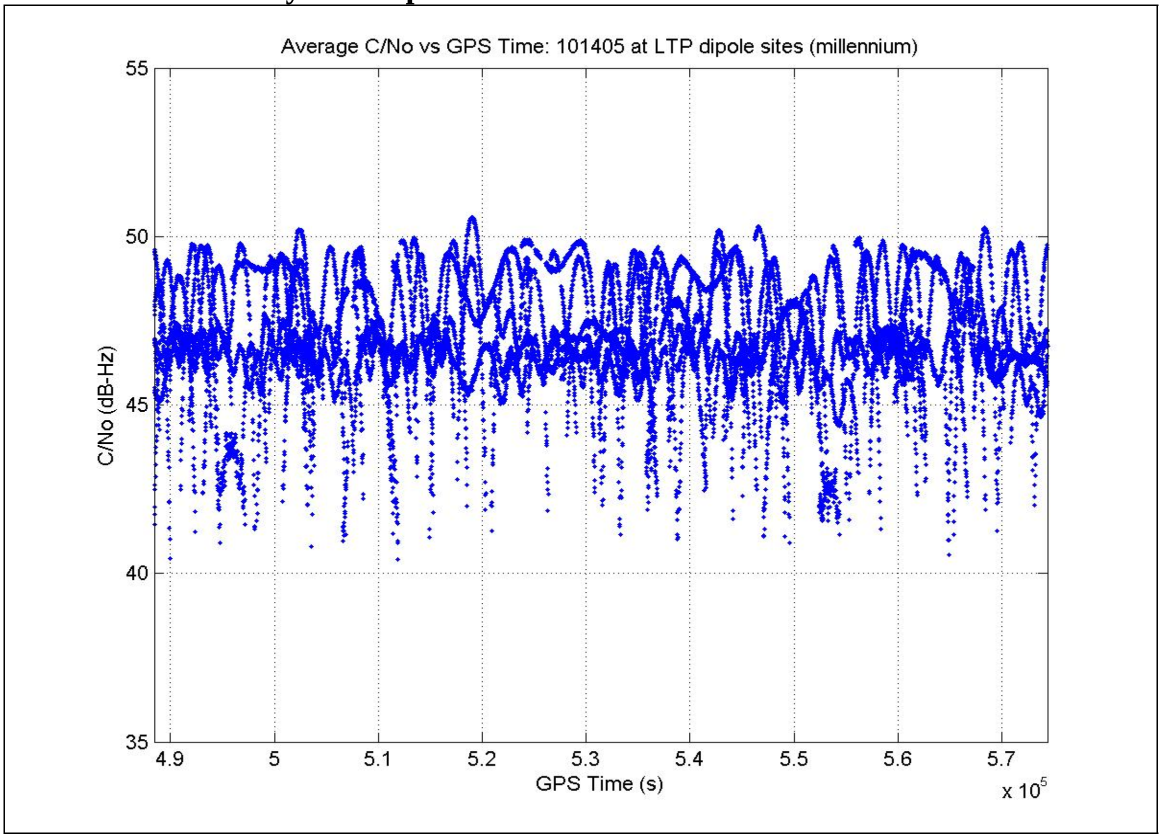
8.9.1.6.5 October System Dipole CMC versus Time



8.9.1.6.6 October System Dipole Carrier to Noise versus Elevation

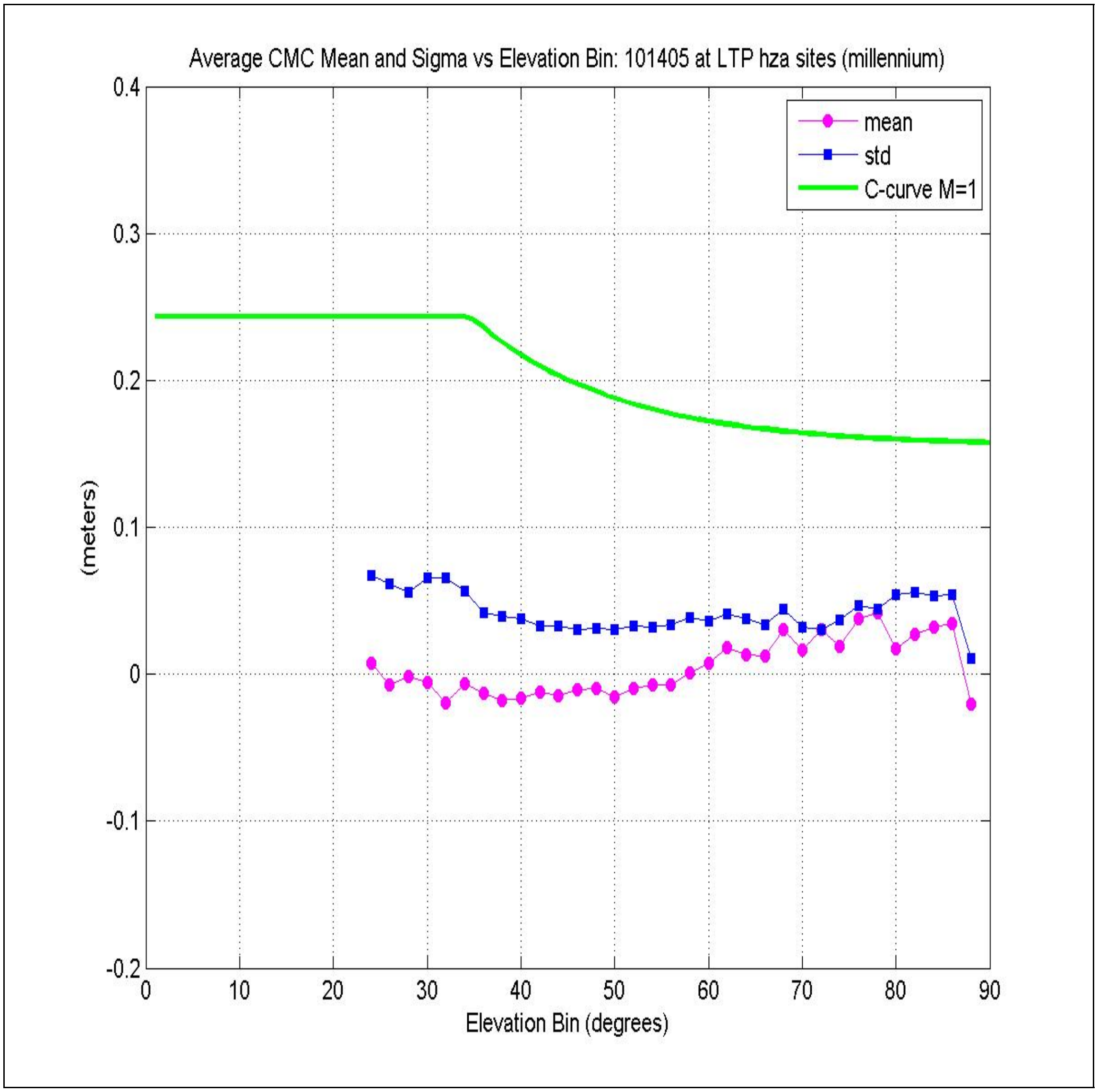


8.9.1.6.7 October System Dipole Carrier to Noise versus Time

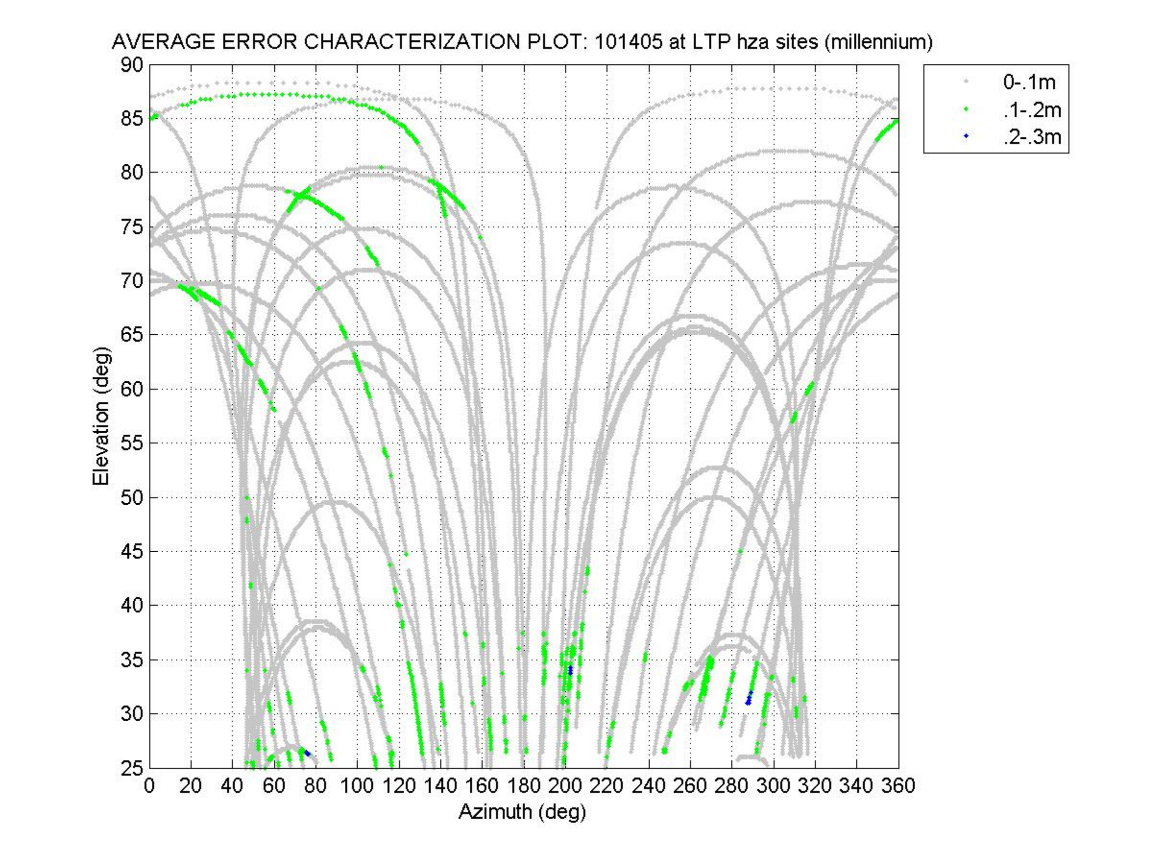


8.9.1.7 October HZA Status and CMC (System Average) (multiple)

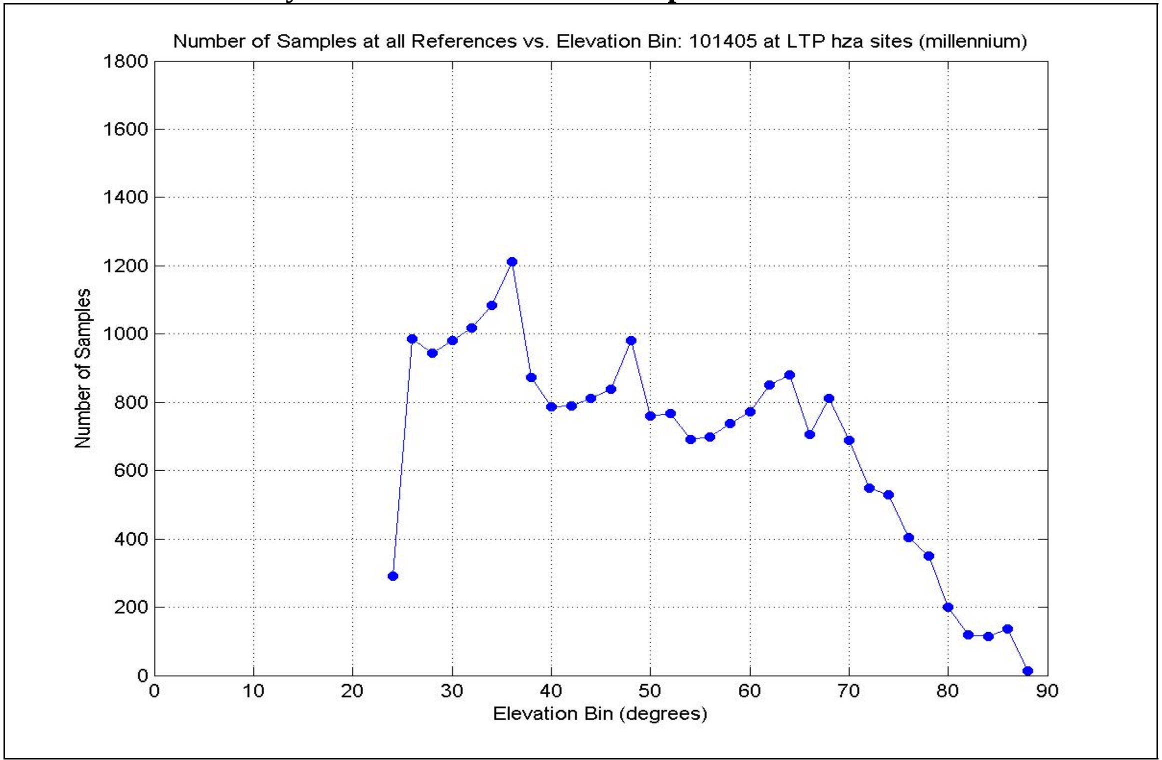
8.9.1.7.1 October System HZA CMC Standard Deviation and Mean versus Elevation



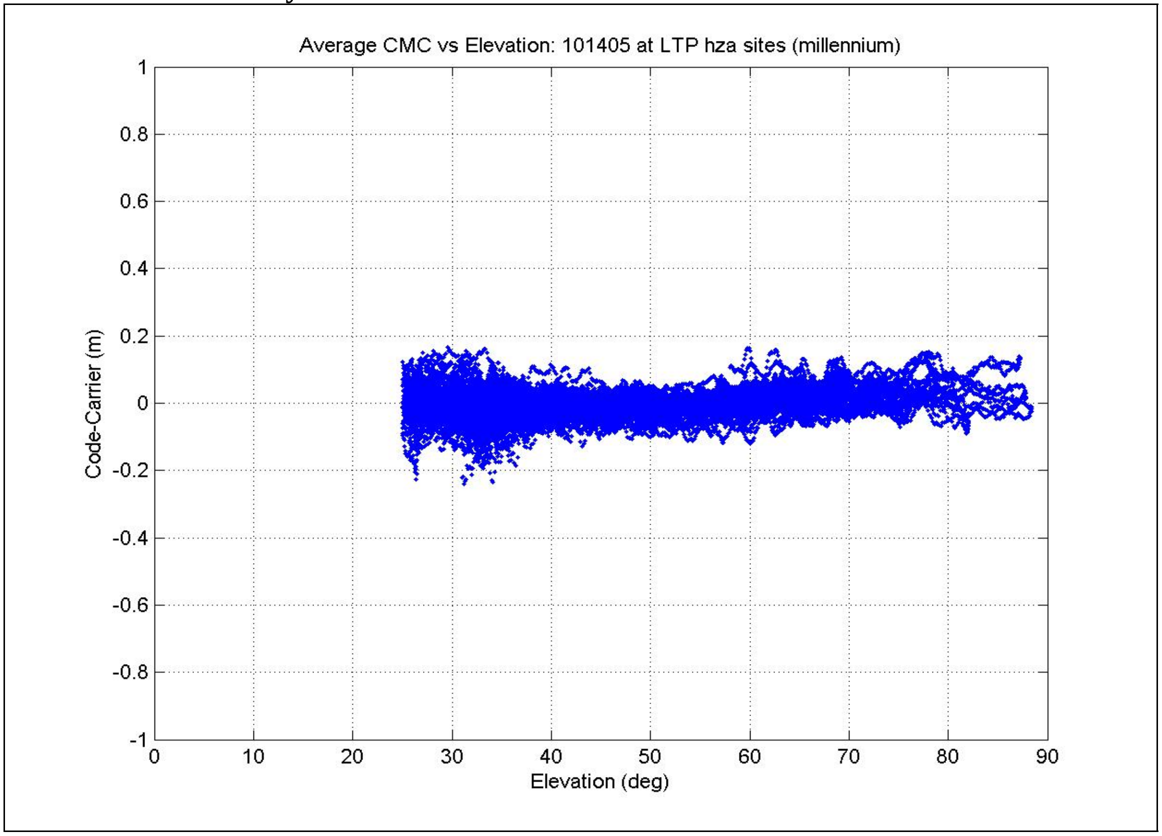
8.9.1.7.2 October System HZA Error Characterization versus Azimuth and Elevation



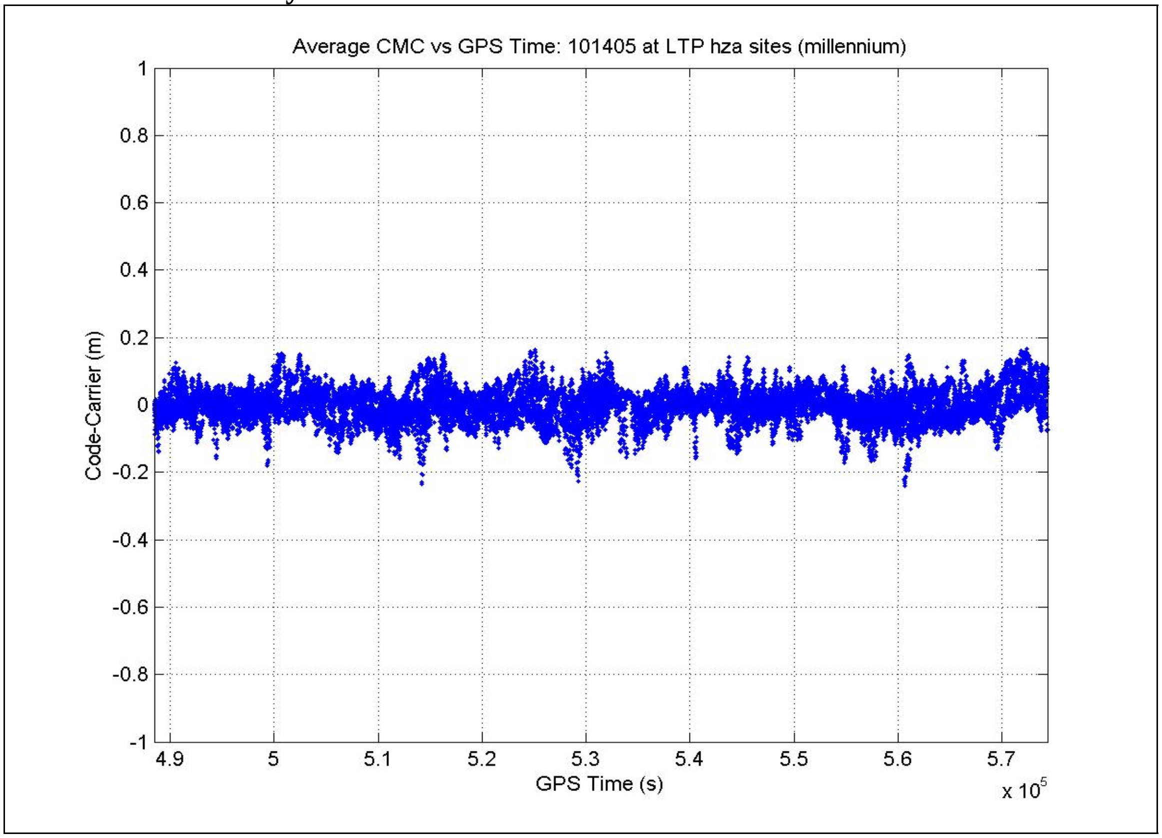
8.9.1.7.3 October System HZA Number of Samples versus Elevation



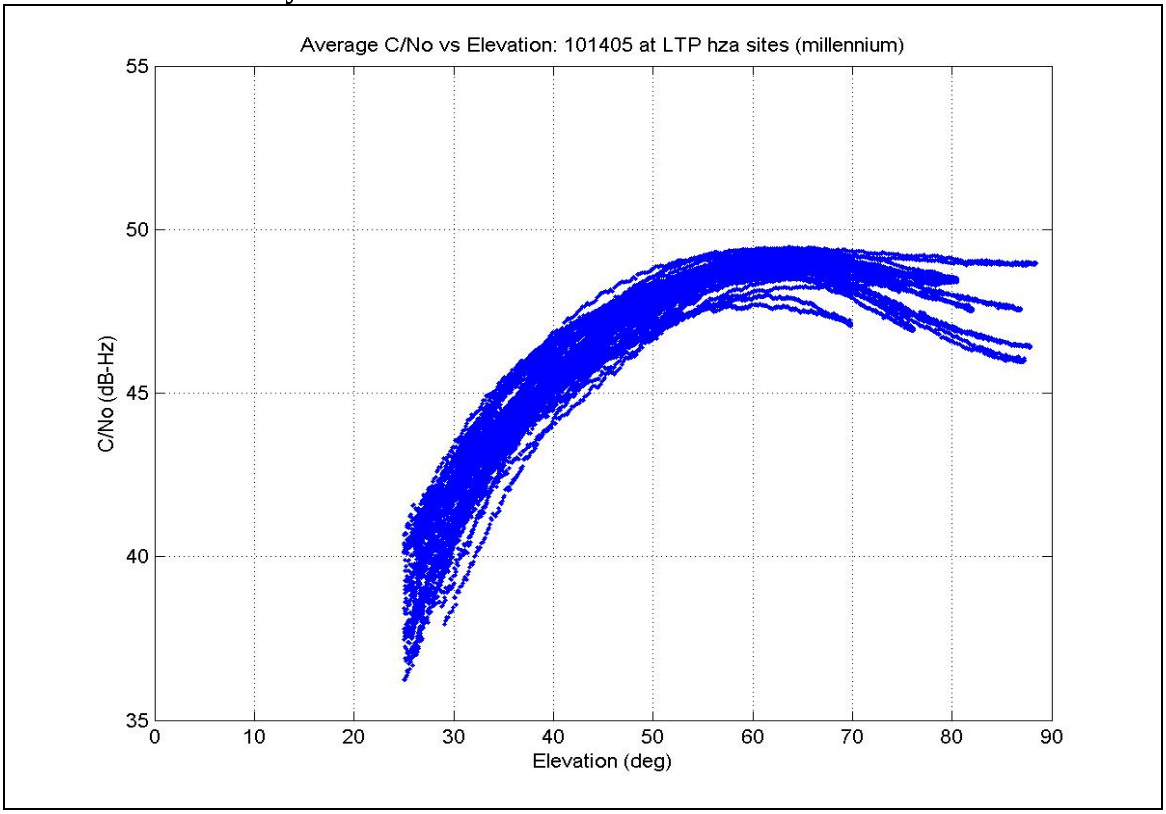
8.9.1.7.4 October System HZA CMC versus Elevation



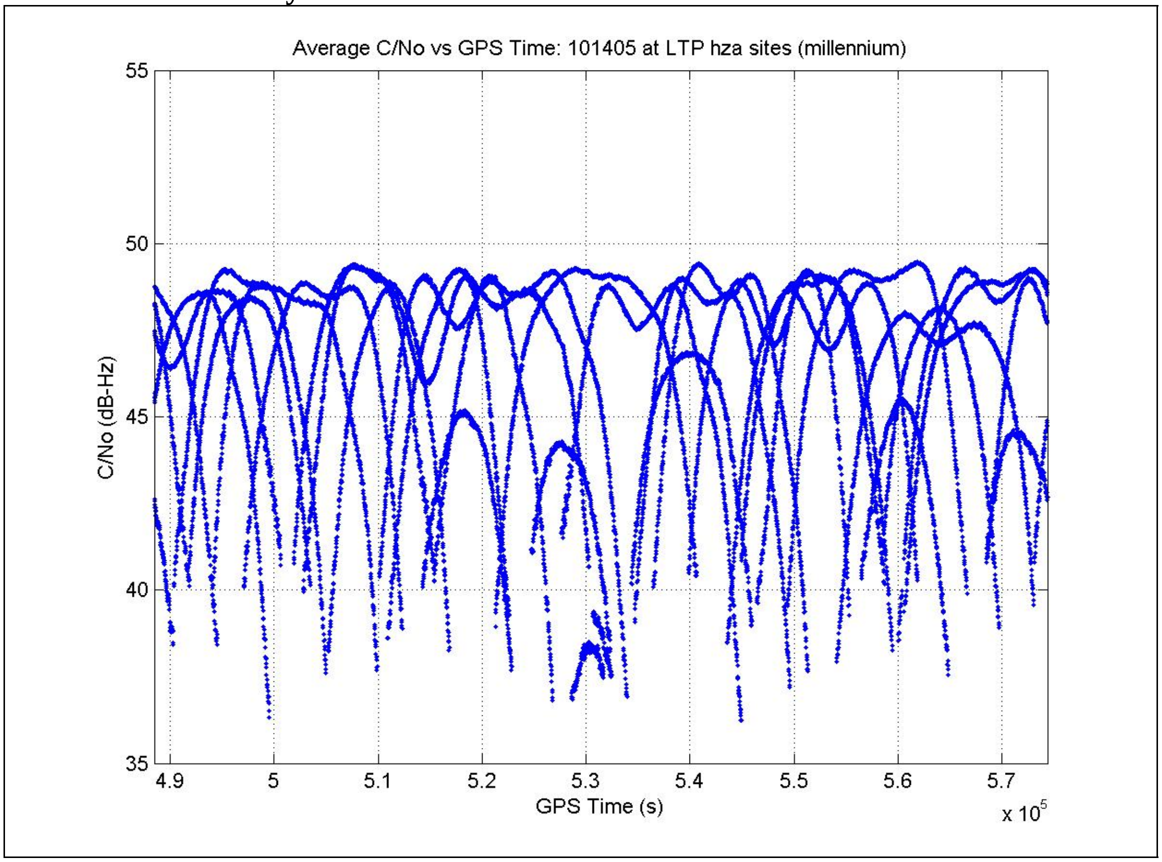
8.9.1.7.5 October System HZA CMC versus Time



8.9.1.7.6 October System HZA Carrier to Noise versus Elevation

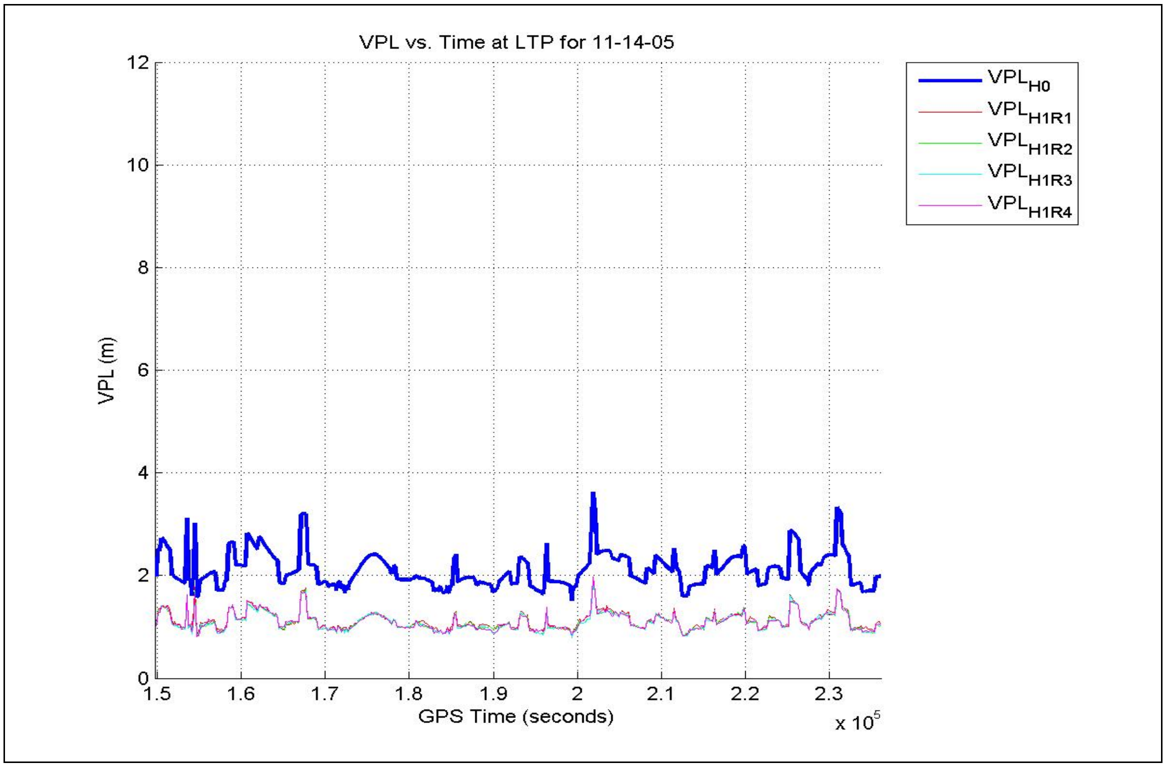


8.9.1.7.7 October System HZA Carrier to Noise versus Time

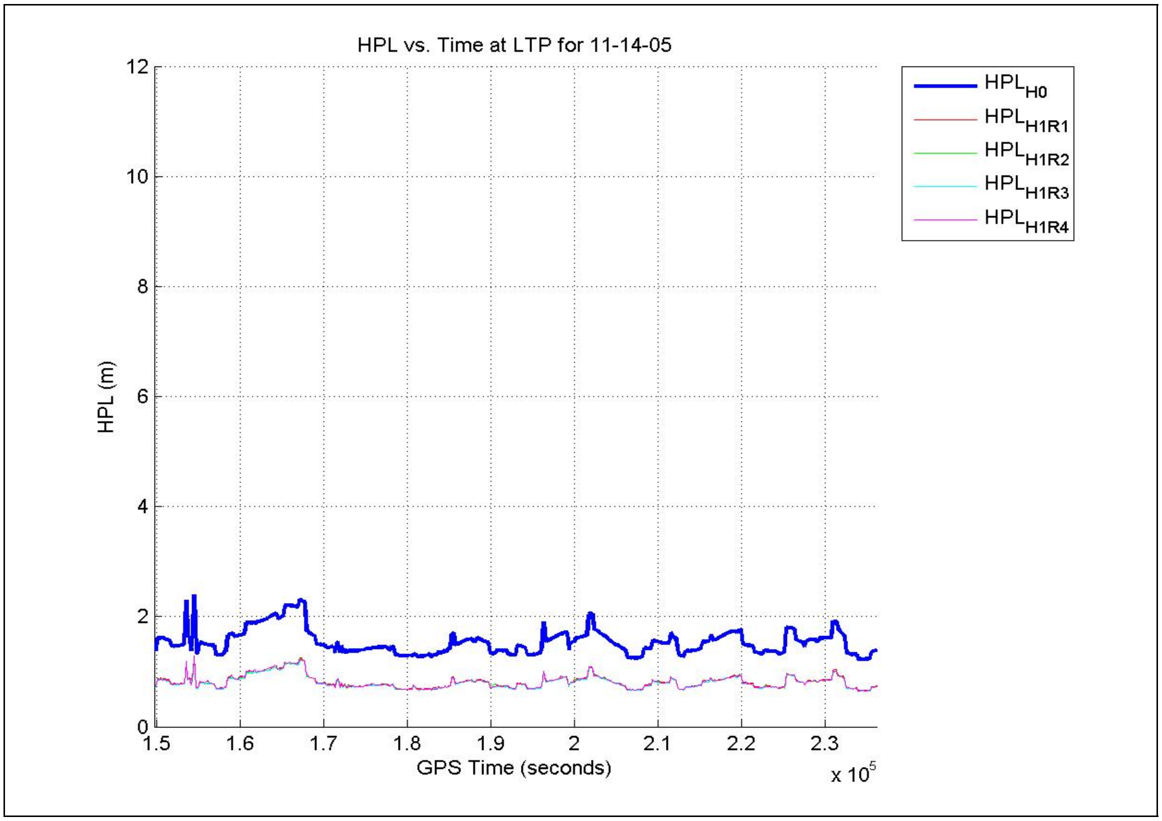


8.9.2 November 2005 Performance Plots

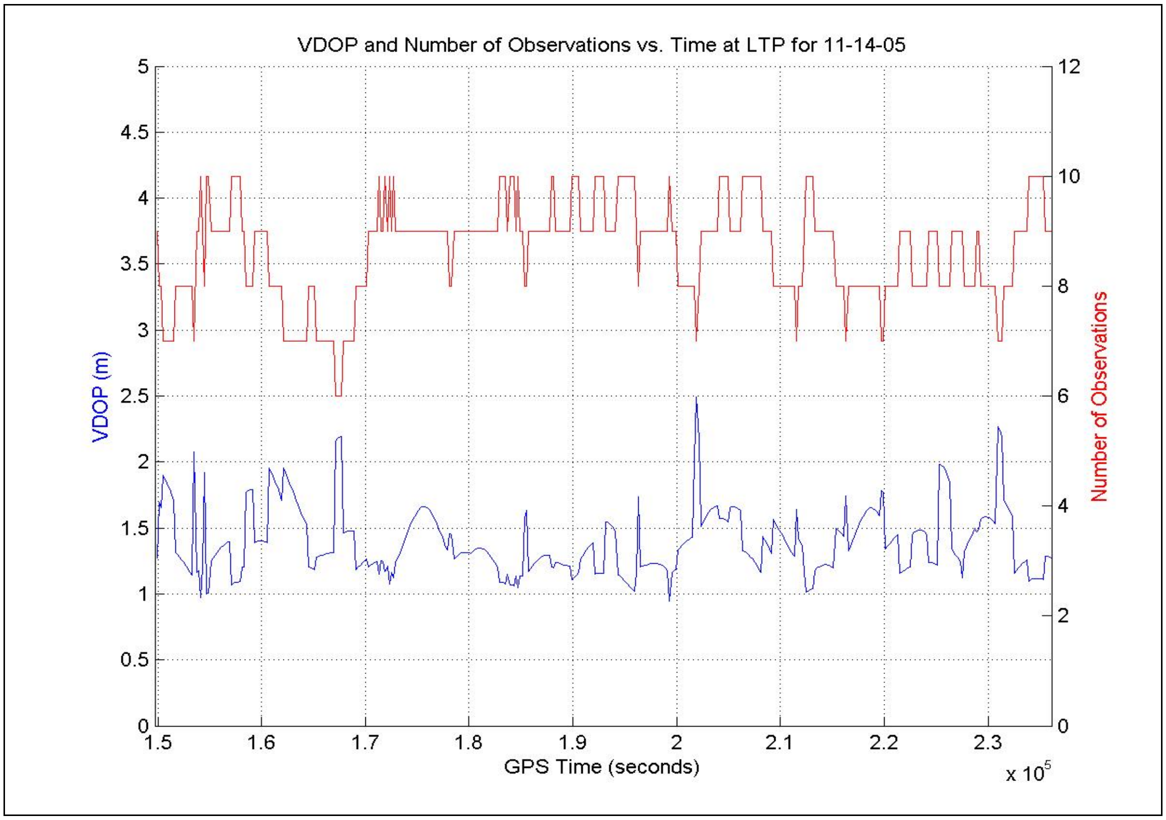
8.9.2.1 November VPL versus Time



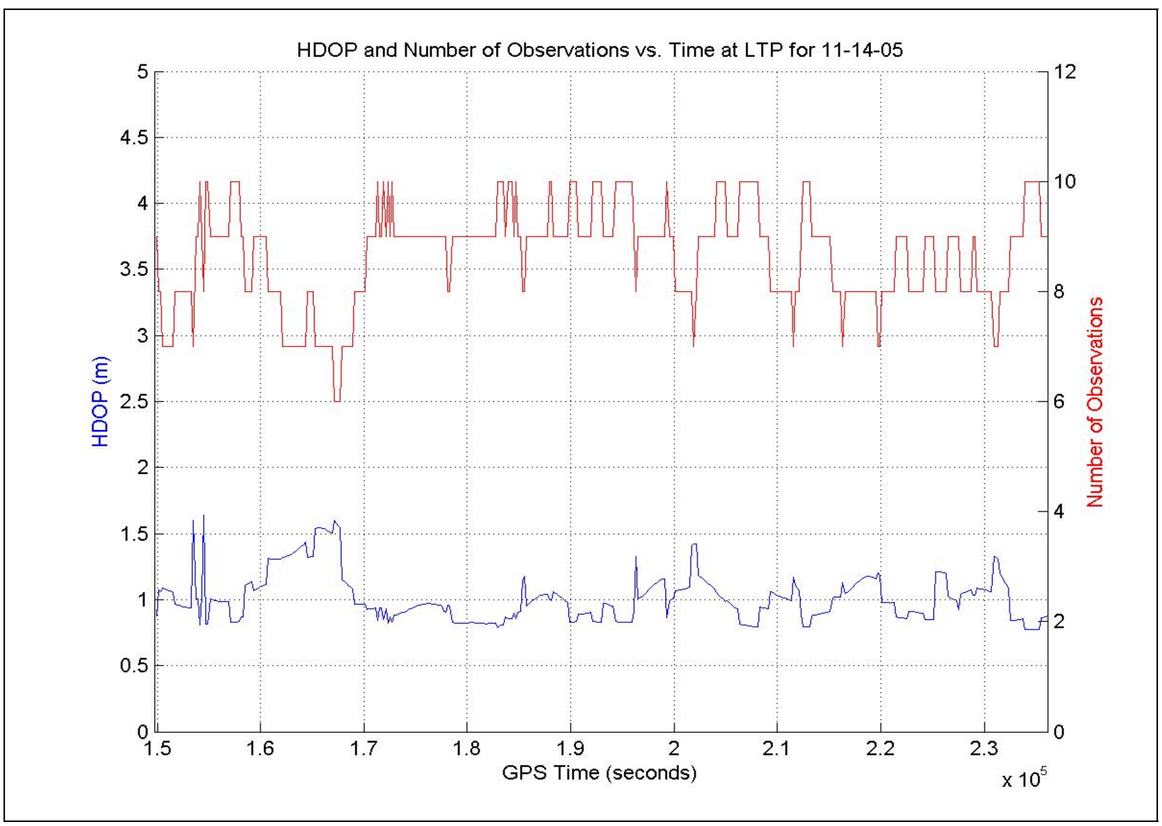
8.9.2.2 November HPL versus Time



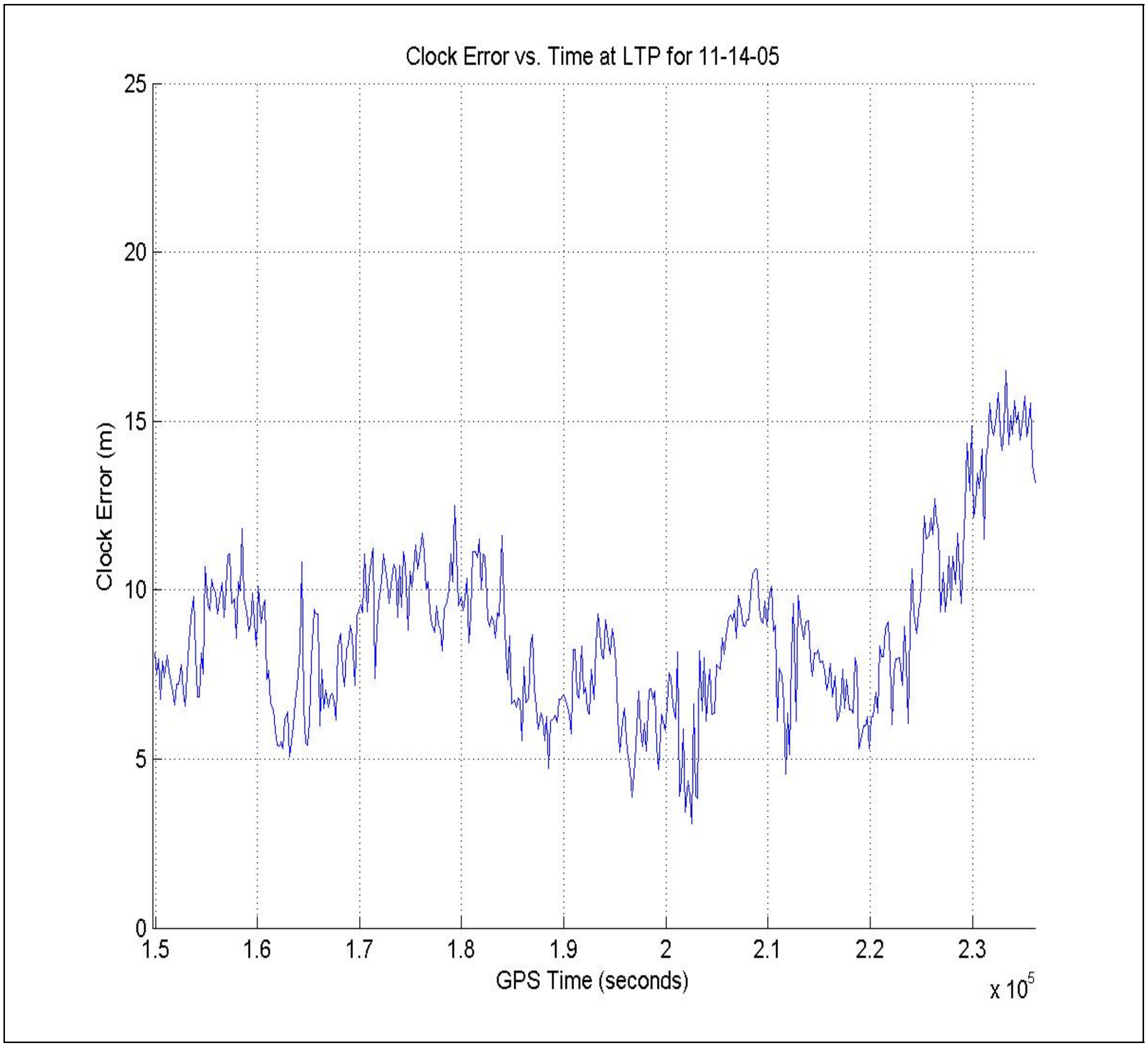
8.9.2.3 November VDOP and # of SV Observations versus Time



8.9.2.4 November HDOP and # of SV Observations versus Time

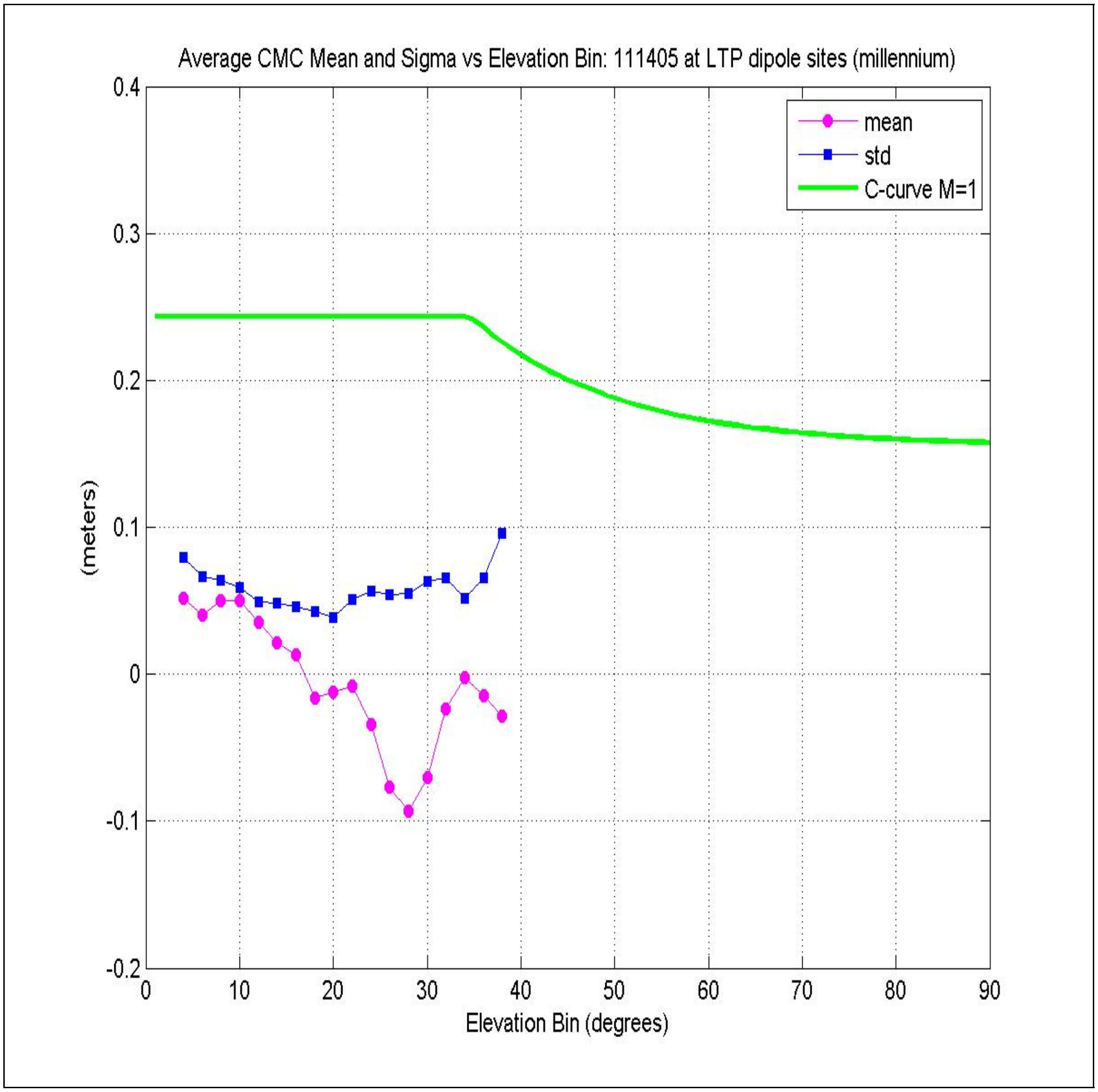


8.9.2.5 November Clock Error versus Time

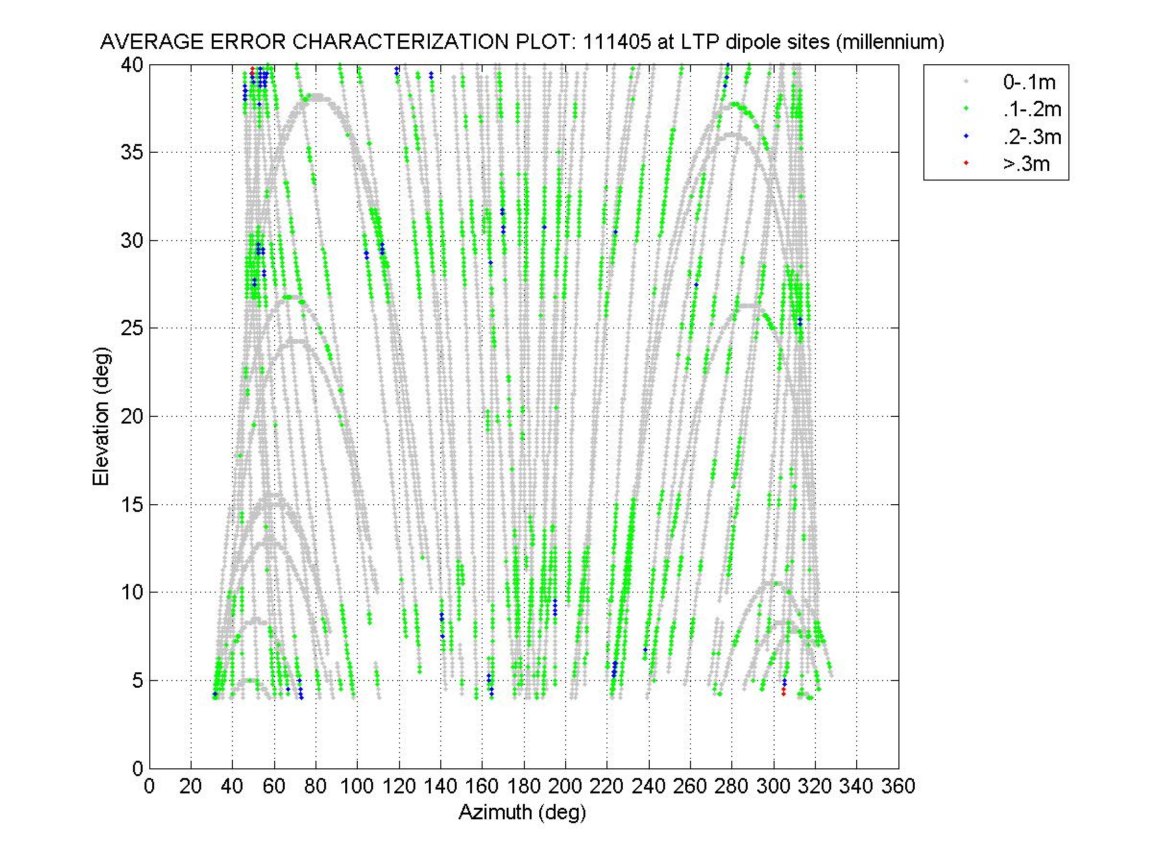


8.9.2.6 November Dipole Status and CMC (System Average) (multiple)

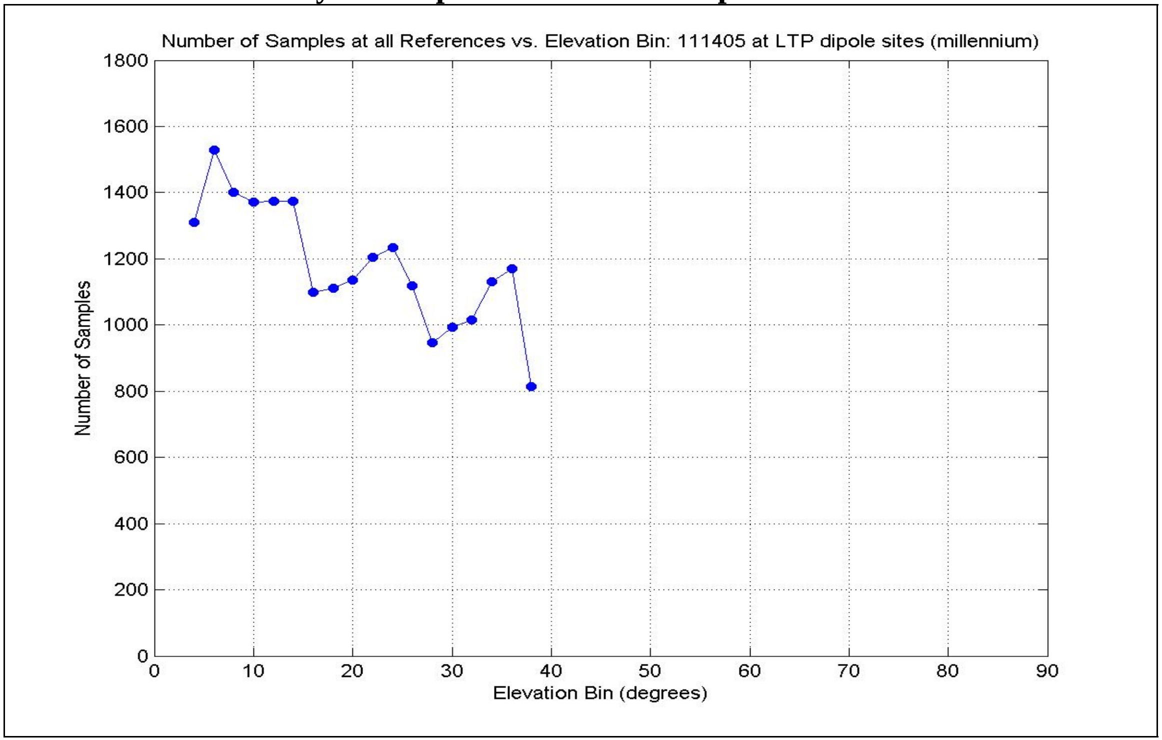
8.9.2.6.1 November System Dipole CMC Standard Deviation and Mean versus Elevation



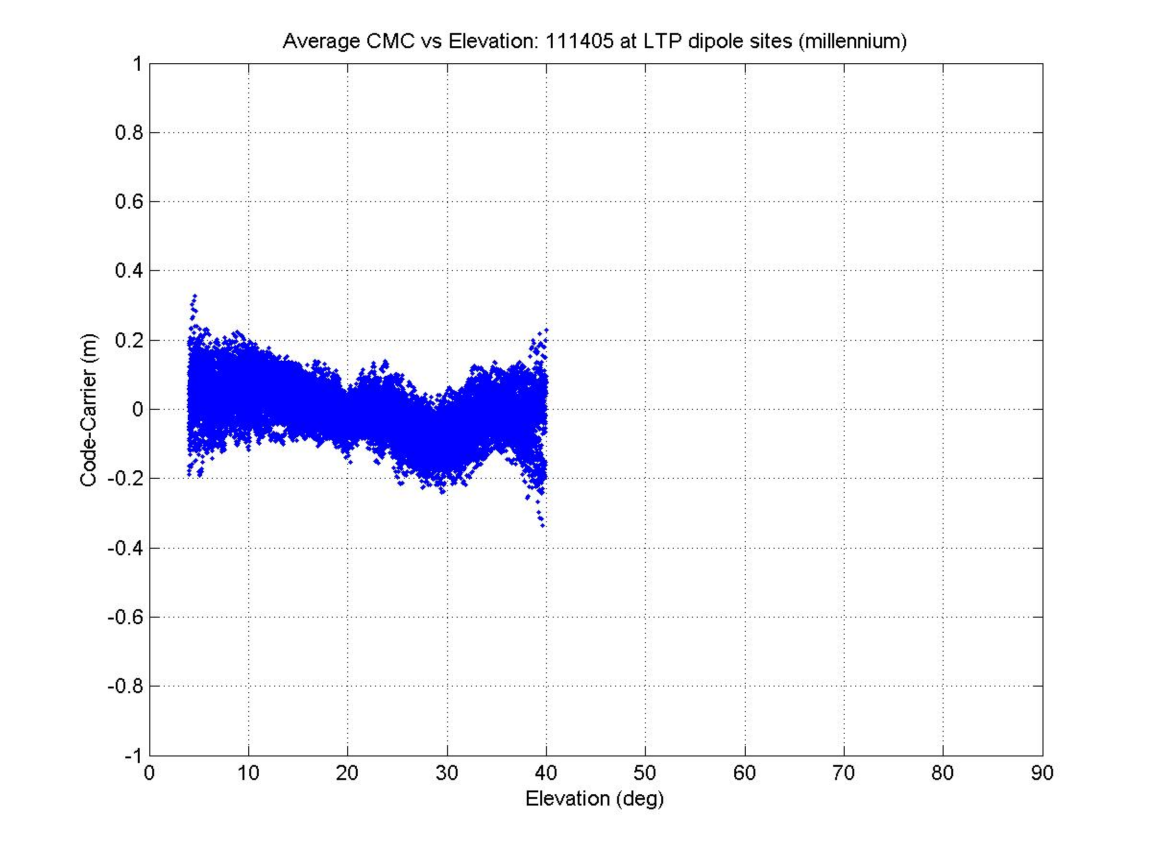
8.9.2.6.2 November System Dipole Error Characterization versus Azimuth and Elevation



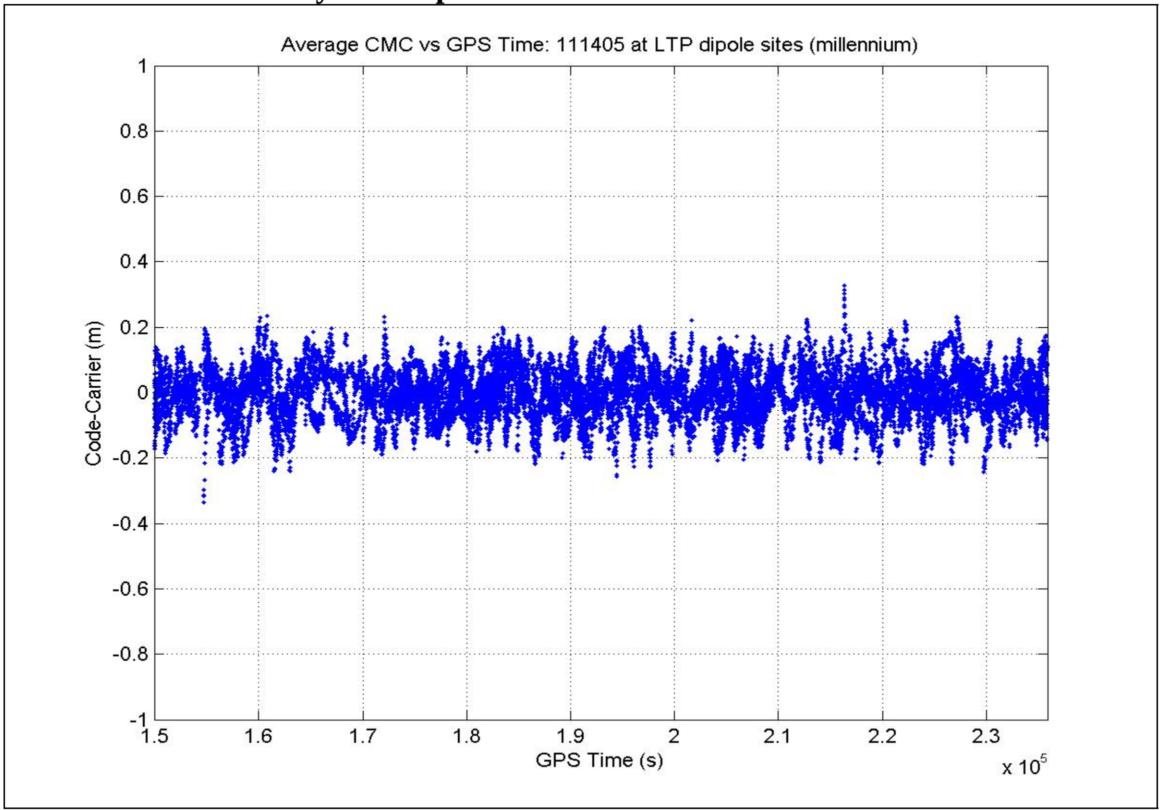
8.9.2.6.3 November System Dipole Number of Samples versus Elevation



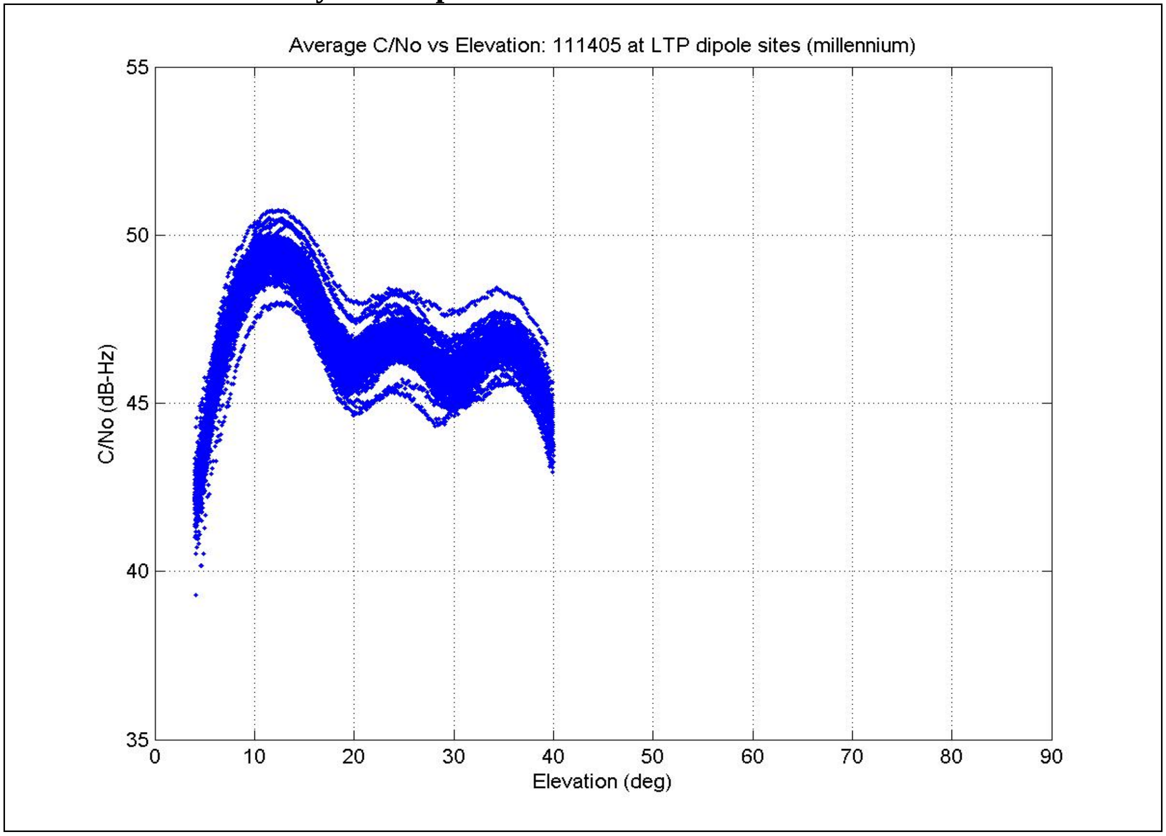
8.9.2.6.4 November System Dipole CMC versus Elevation



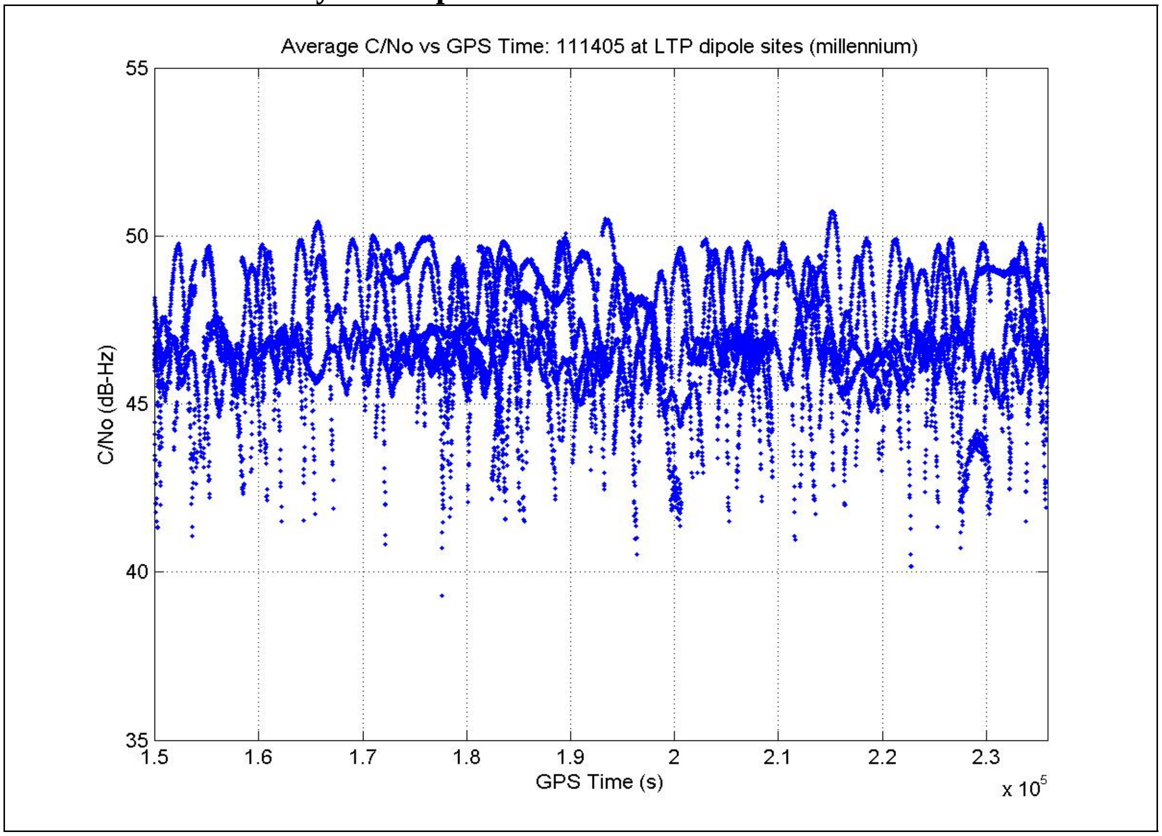
8.9.2.6.5 November System Dipole CMC versus Time



8.9.2.6.6 November System Dipole Carrier to Noise versus Elevation

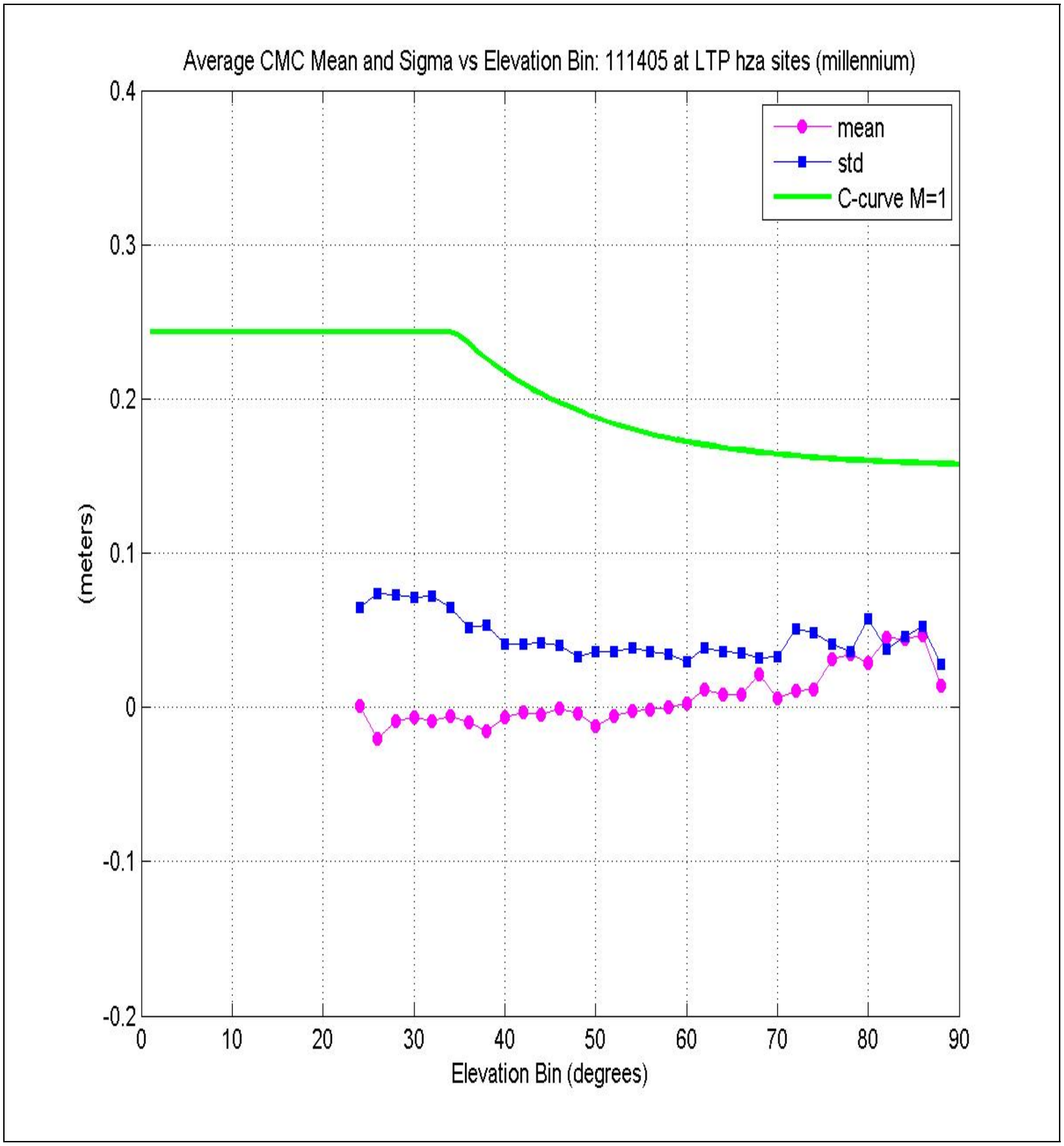


8.9.2.6.7 November System Dipole Carrier to Noise versus Time

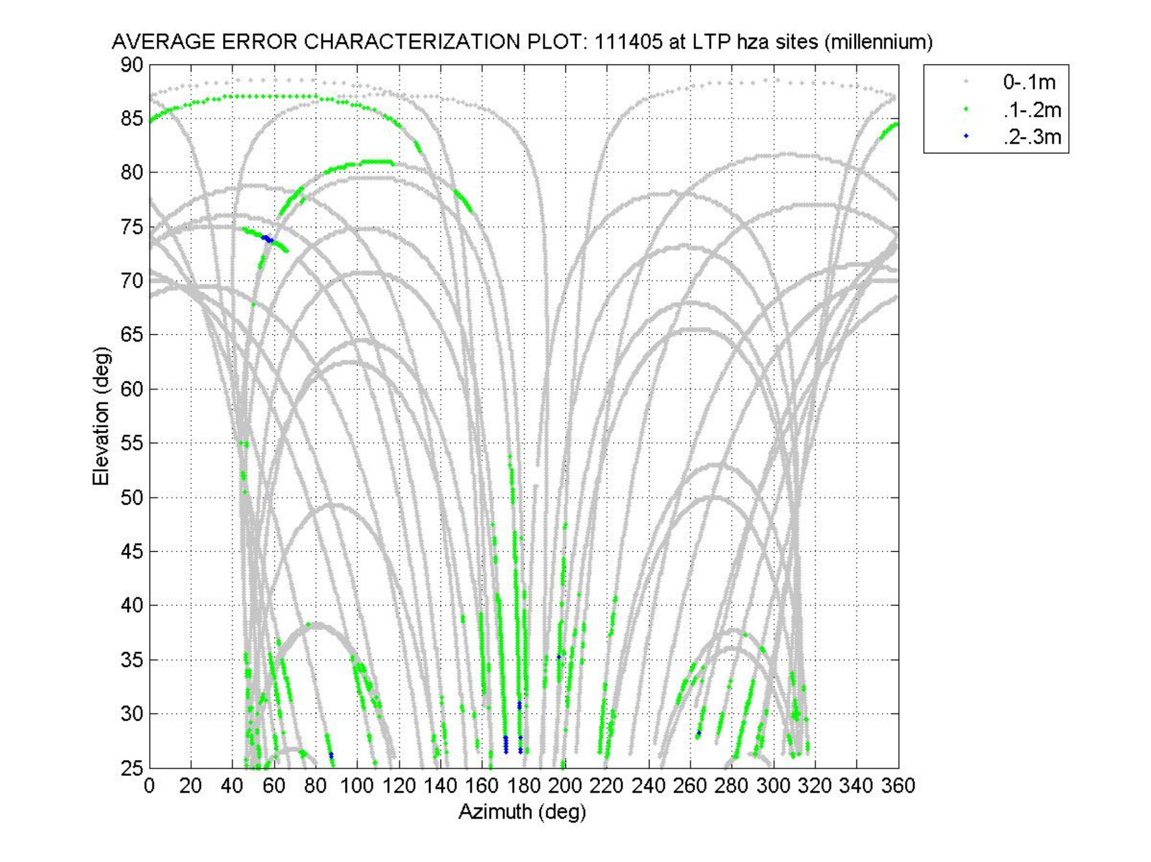


8.9.2.7 November HZA Status and CMC (System Average) (multiple)

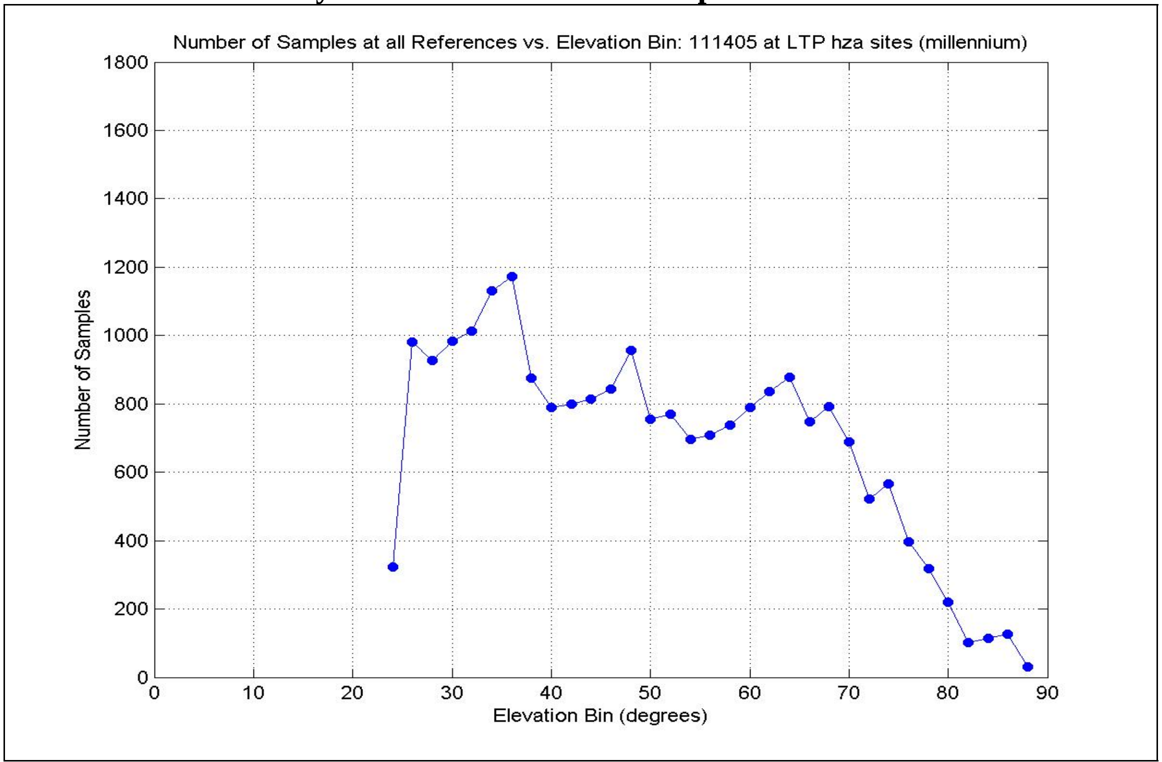
8.9.2.7.1 November System HZA CMC Standard Deviation and Mean versus Elevation



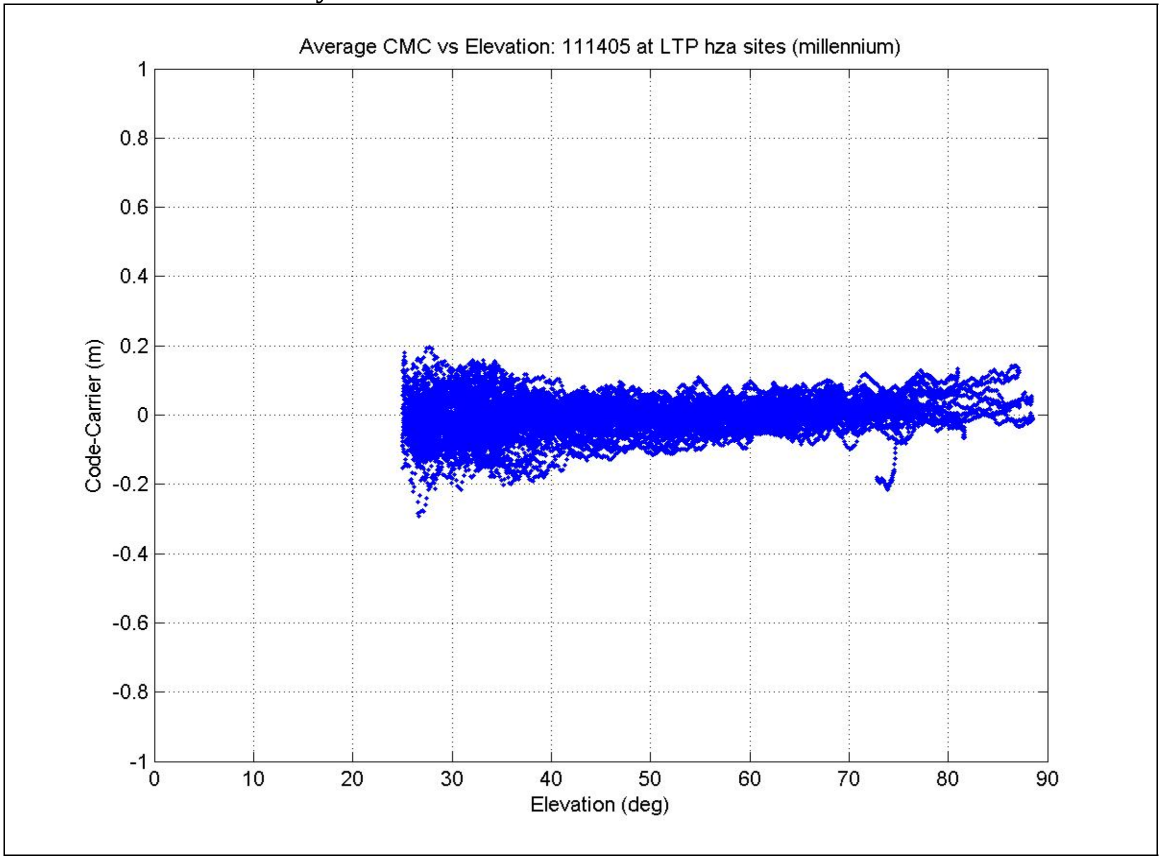
8.9.2.7.2 November System HZA Error Characterization versus Azimuth and Elevation



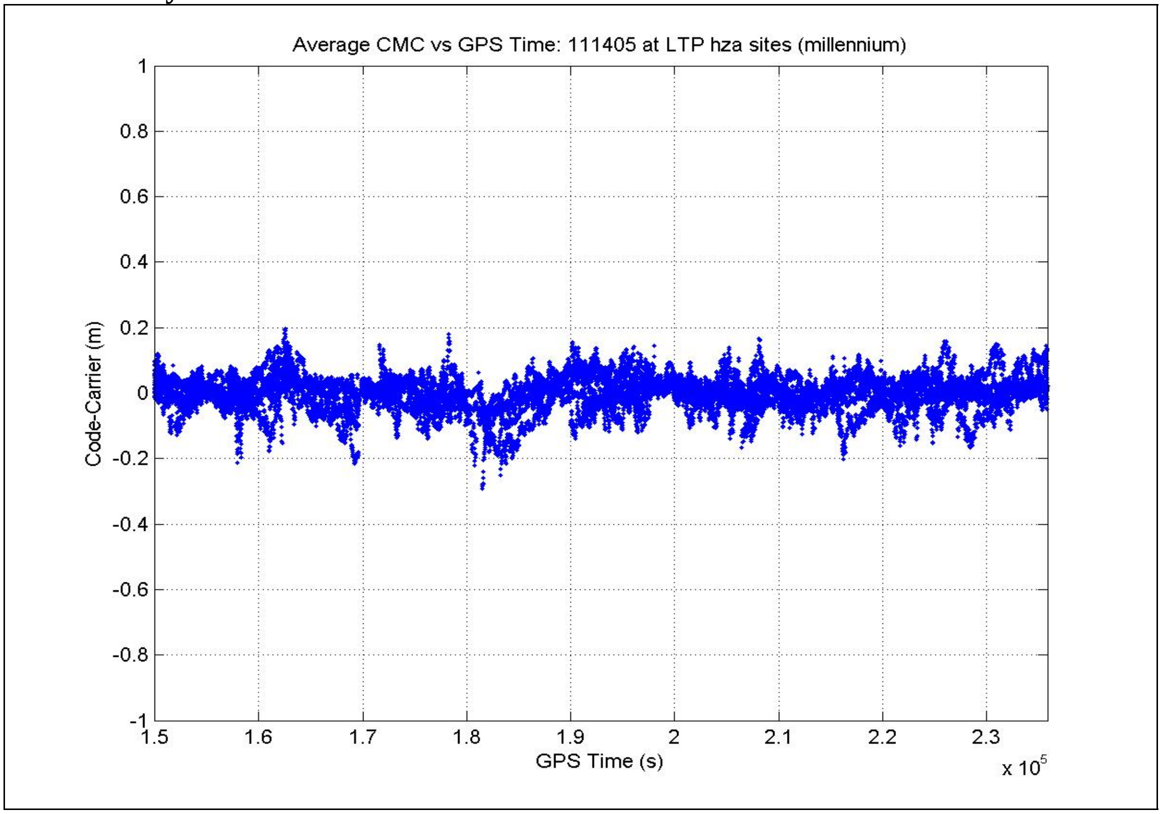
8.9.2.7.3 November System HZA Number of Samples versus Elevation



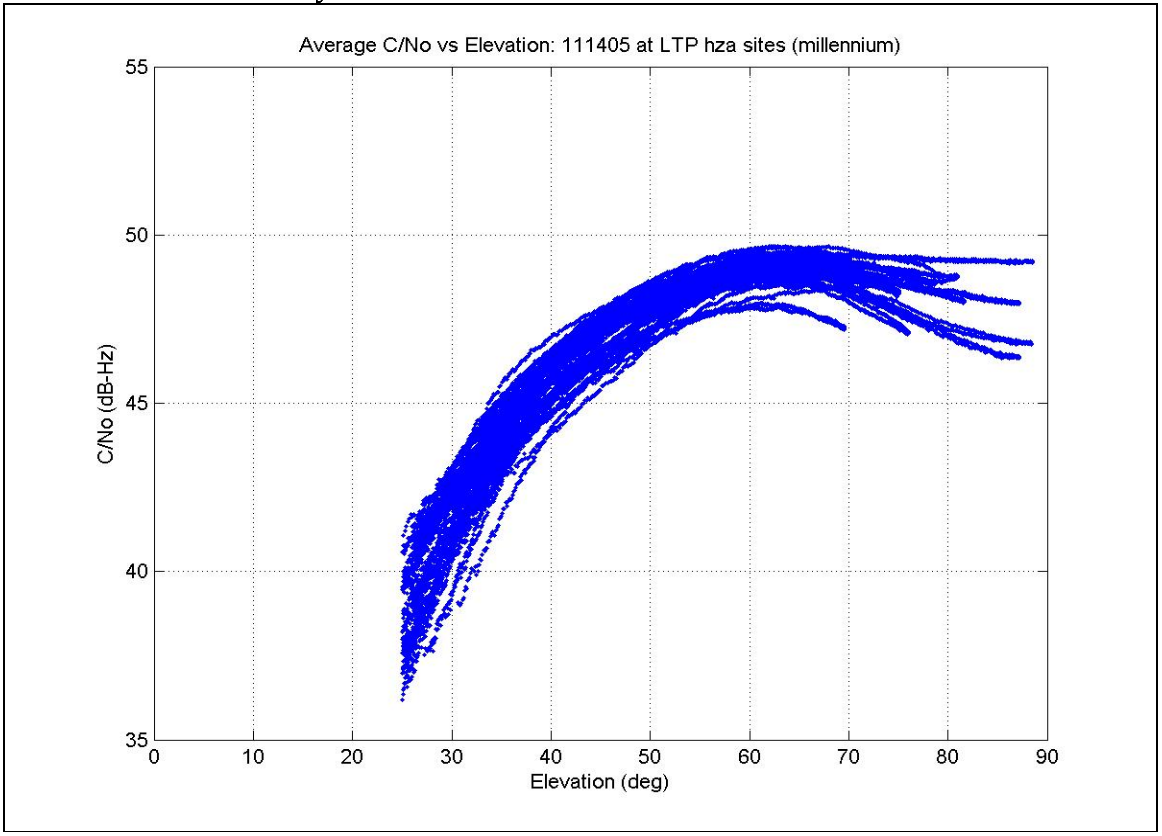
8.9.2.7.4 November System HZA CMC versus Elevation



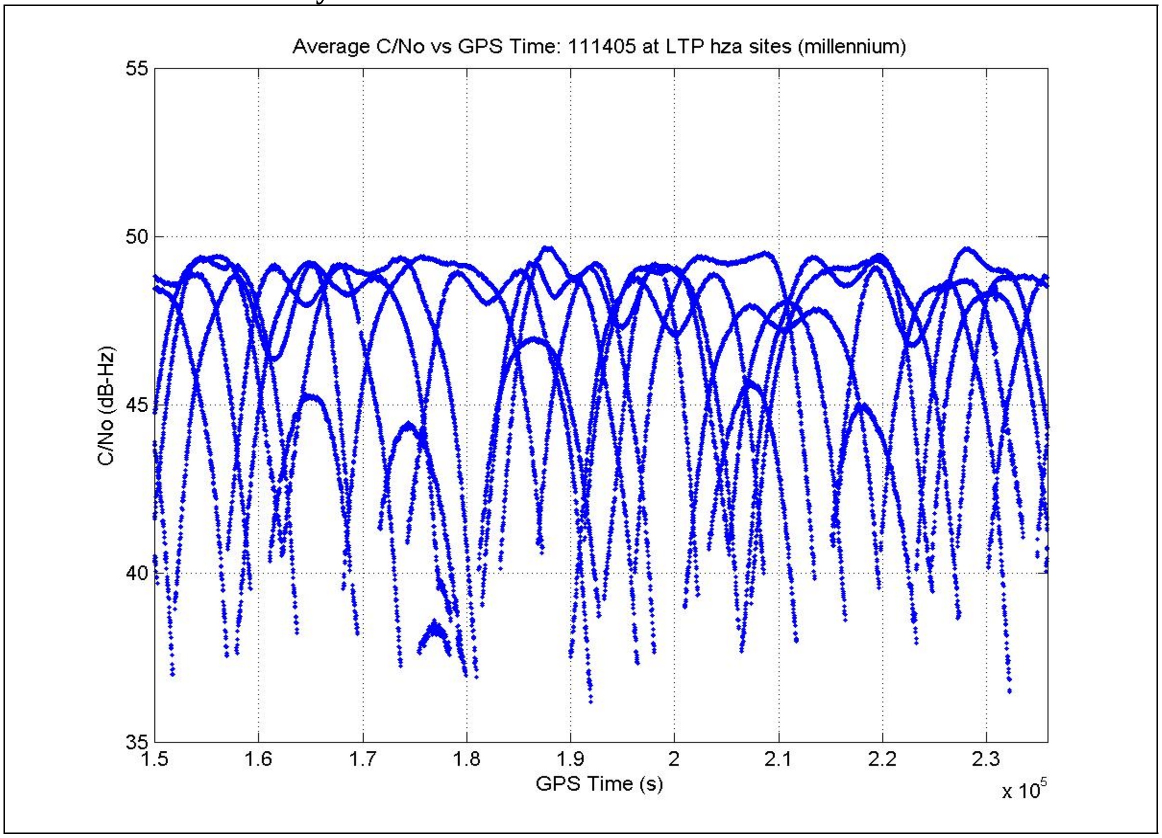
8.9.2.7.5 System HZA CMC versus Time



8.9.2.7.6 November System HZA Carrier to Noise versus Elevation

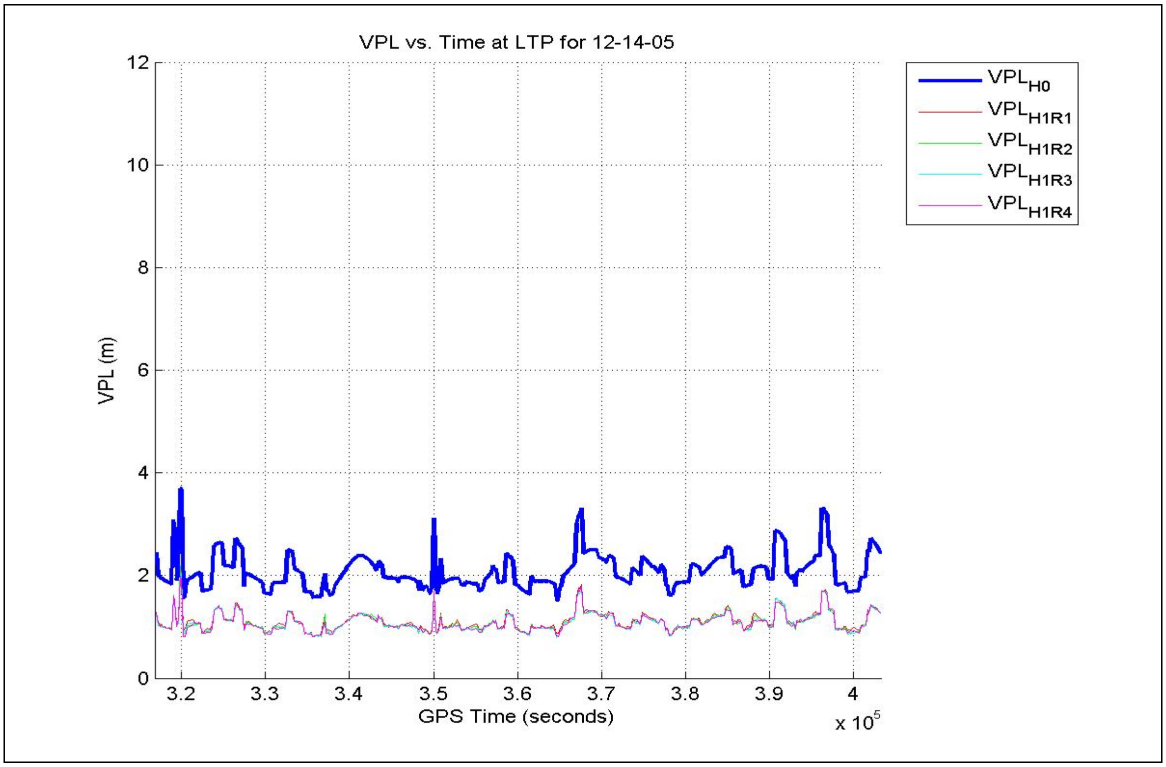


8.9.2.7.7 November System HZA Carrier to Noise versus Time

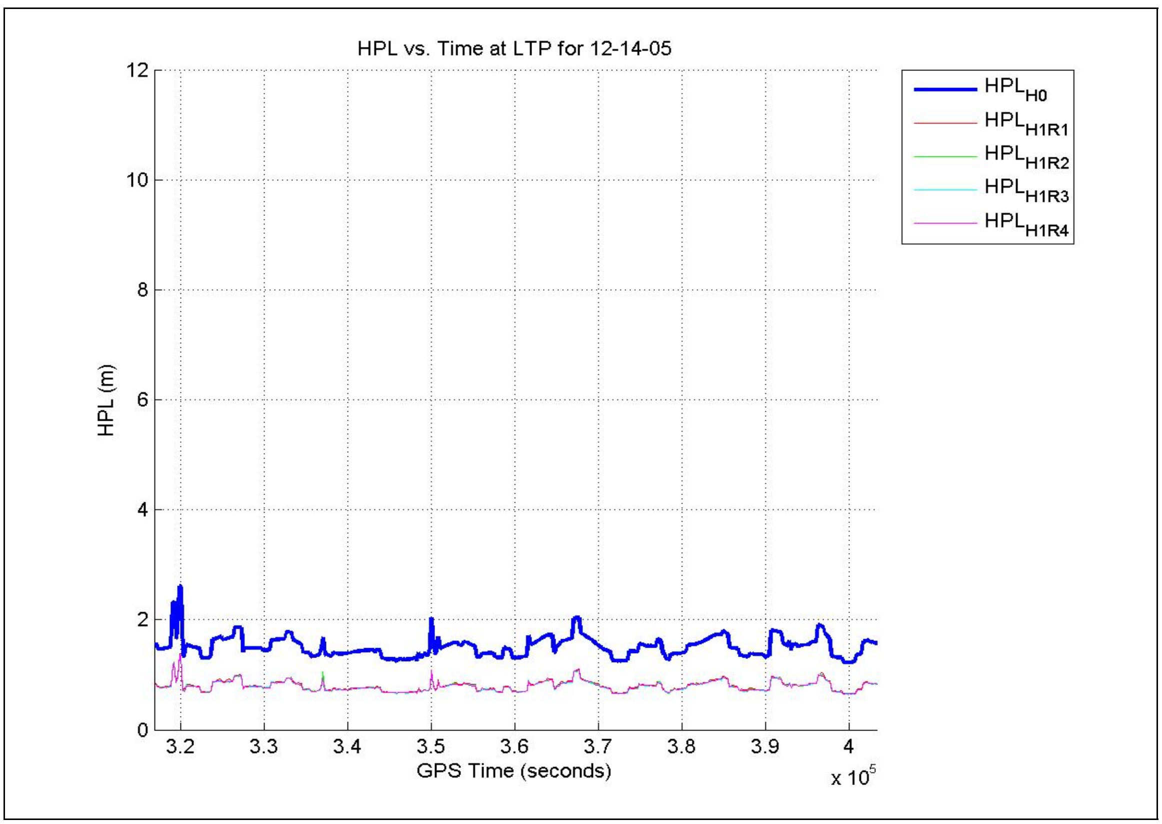


8.9.3 December 2005 Performance Plots

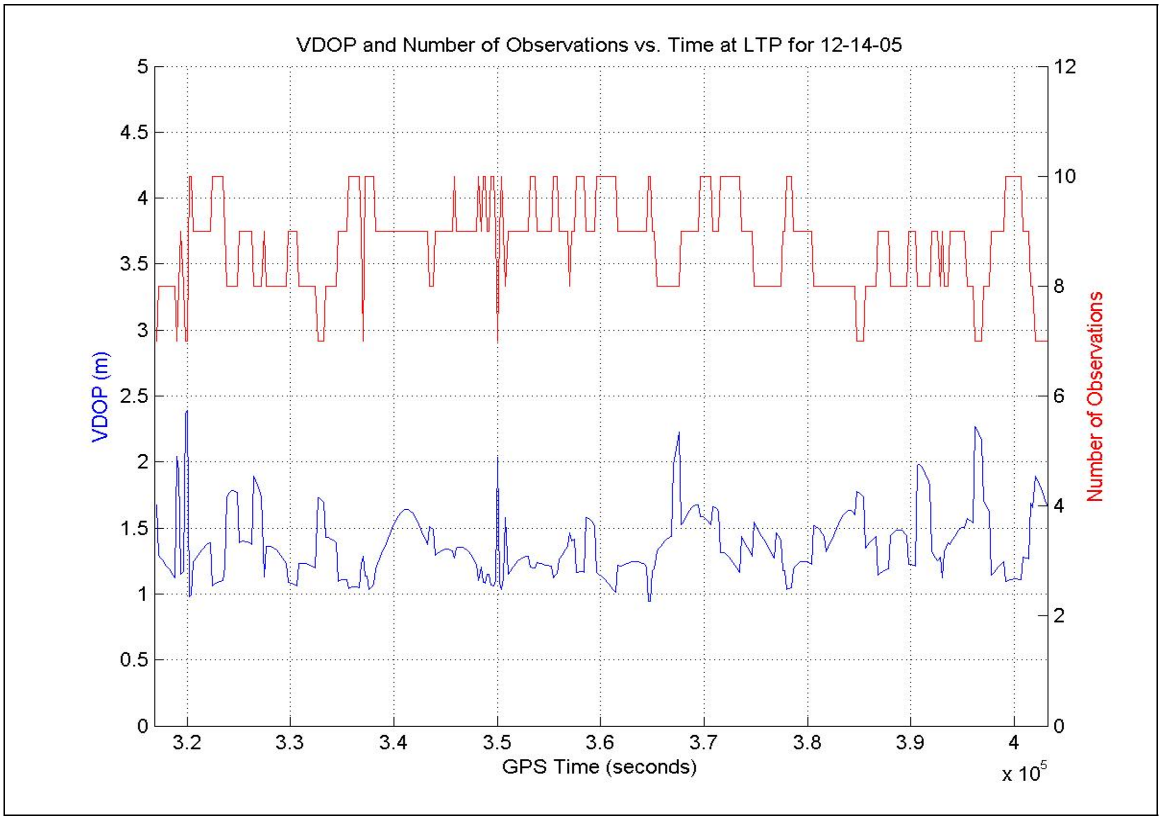
8.9.3.1 December VPL versus Time



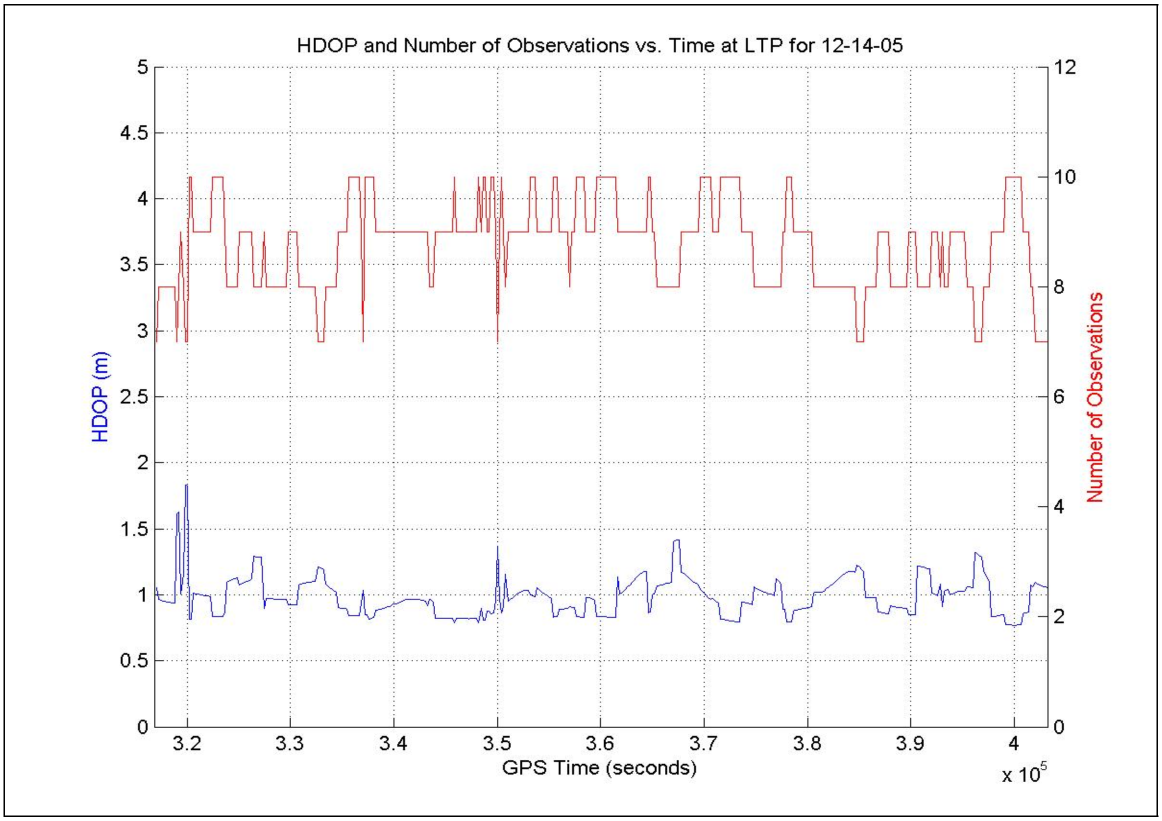
8.9.3.2 December HPL versus Time



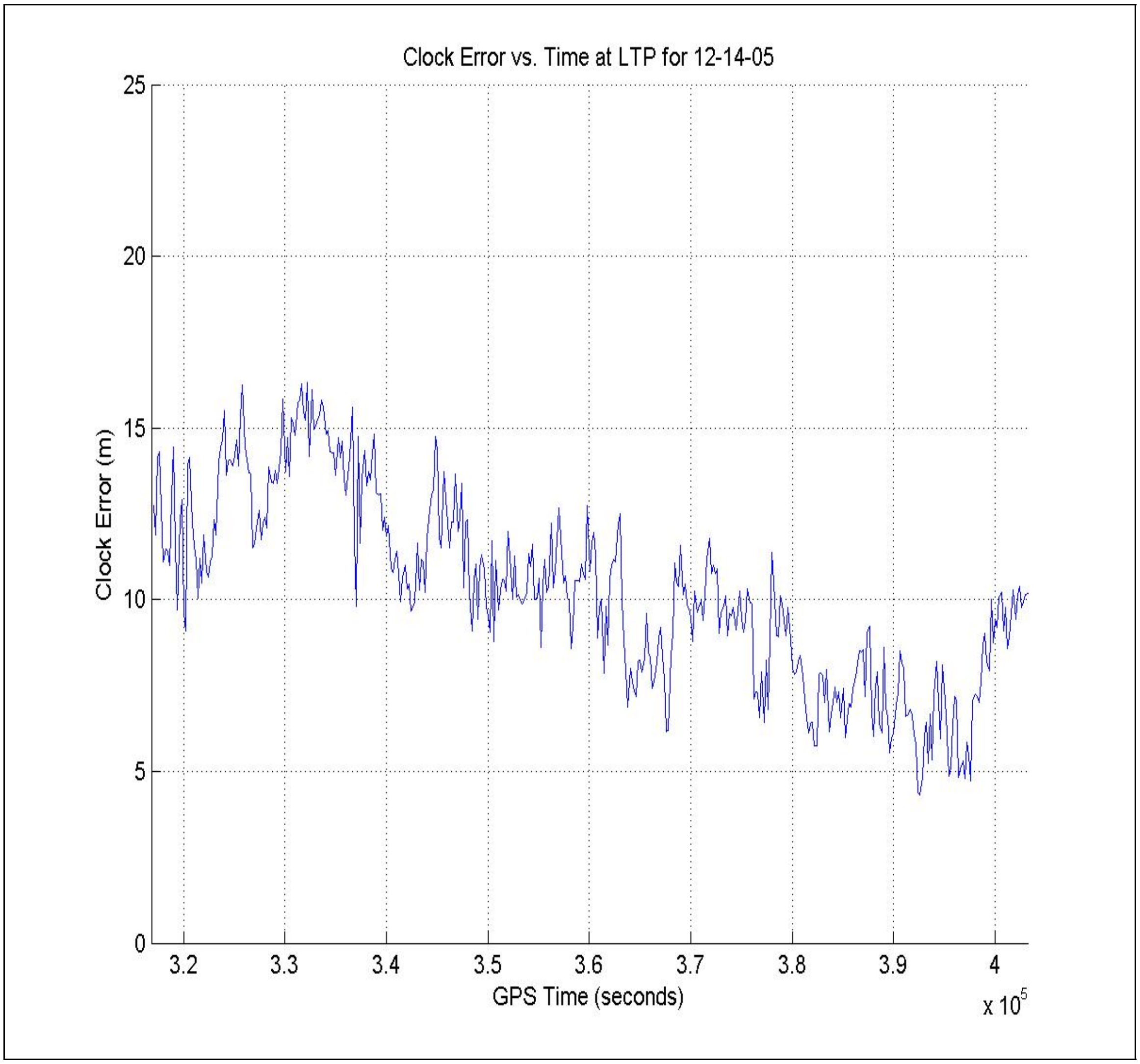
8.9.3.3 December VDOP and # of SV Observations versus Time



8.9.3.4 December HDOP and # of SV Observations versus Time

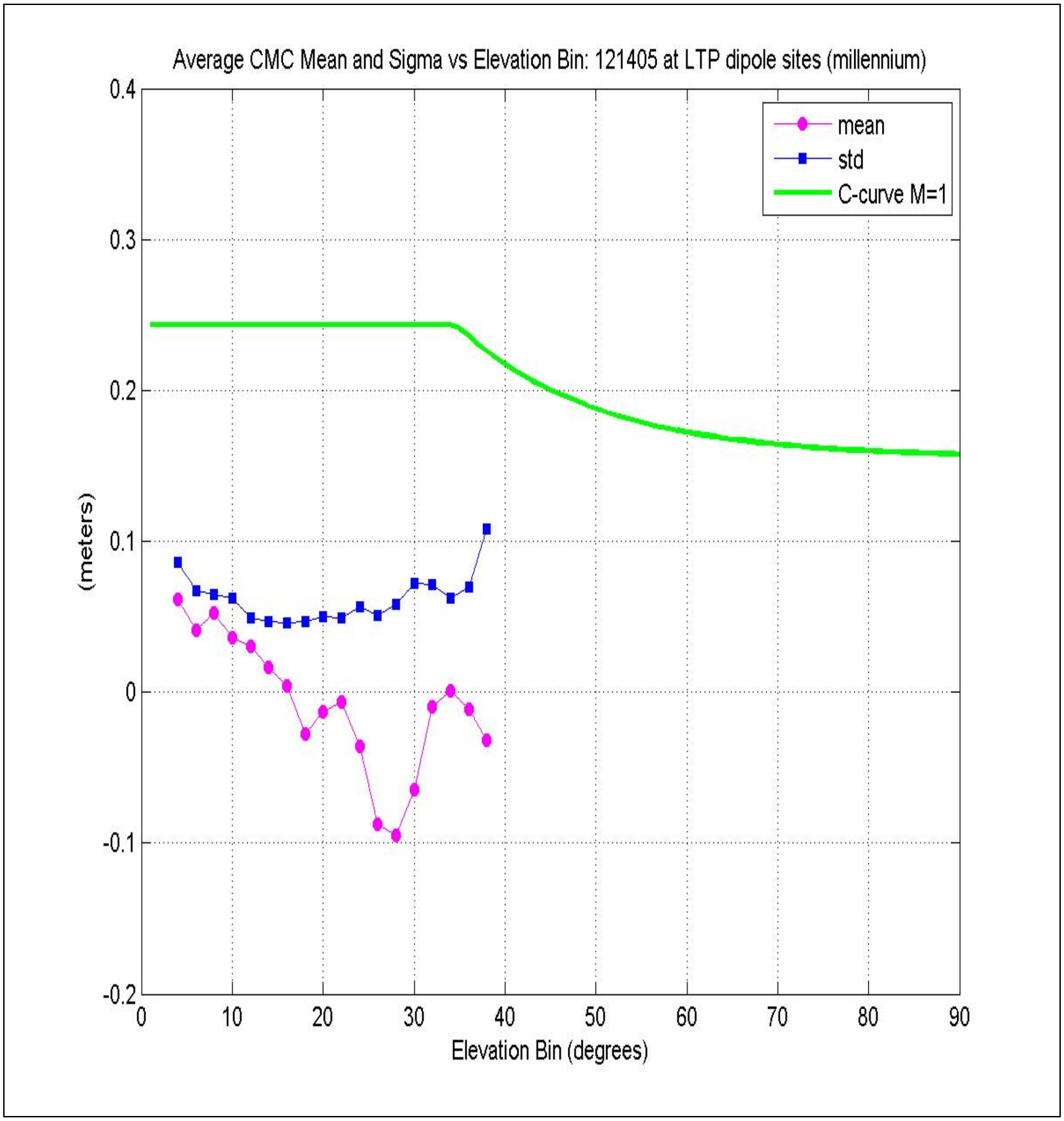


8.9.3.5 December Clock Error versus Time

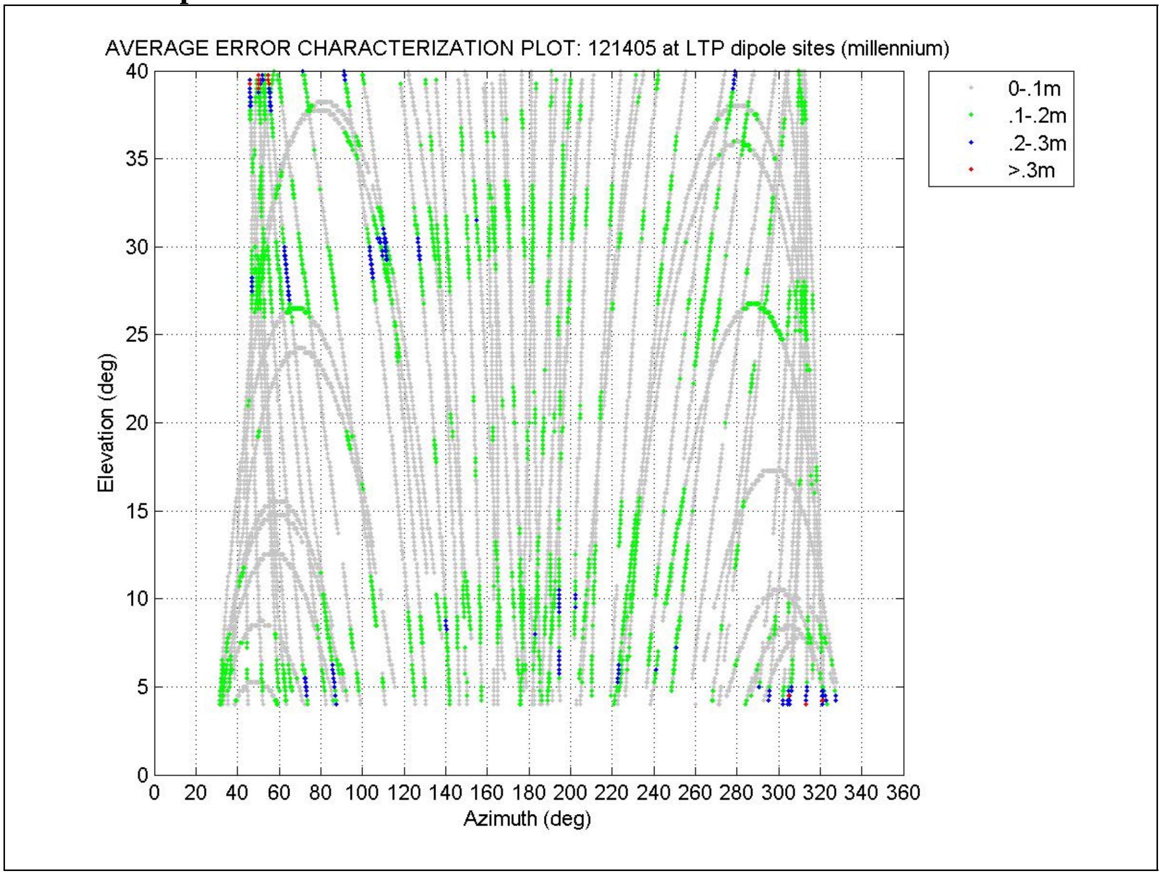


8.9.3.6 December Dipole Status and CMC (System Average) (multiple)

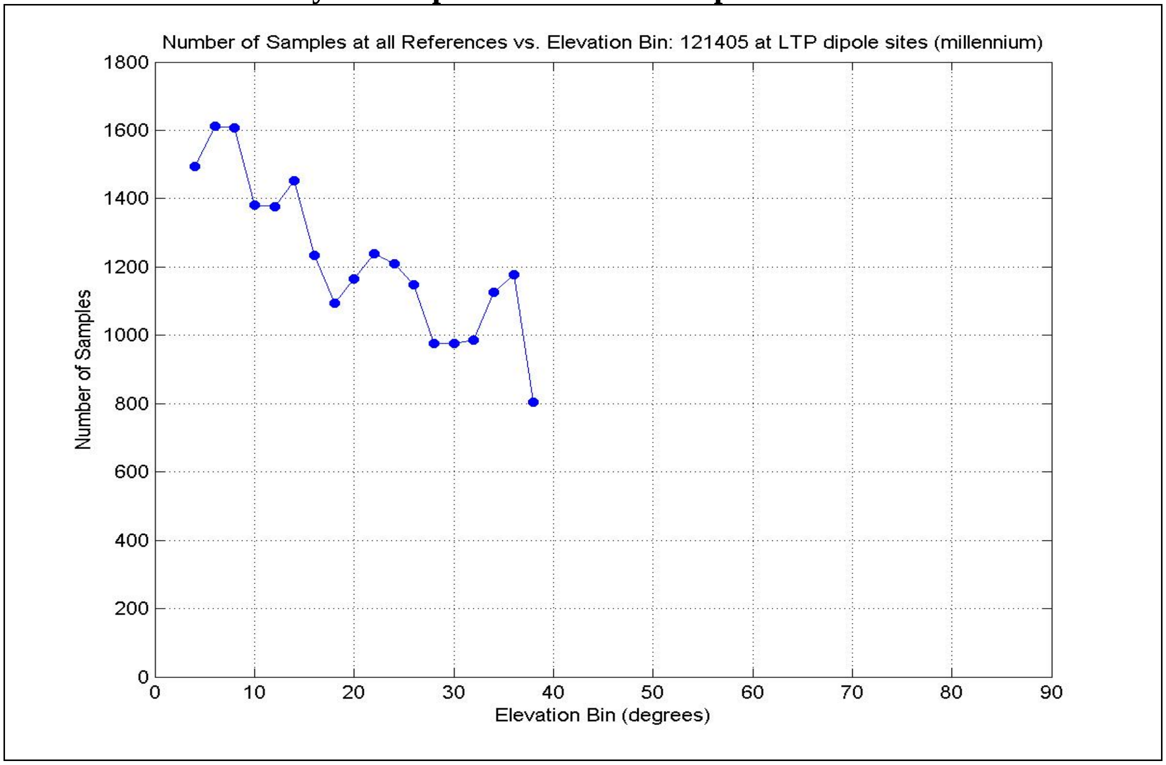
8.9.3.6.8 December System Dipole CMC Standard Deviation and Mean versus Elevation



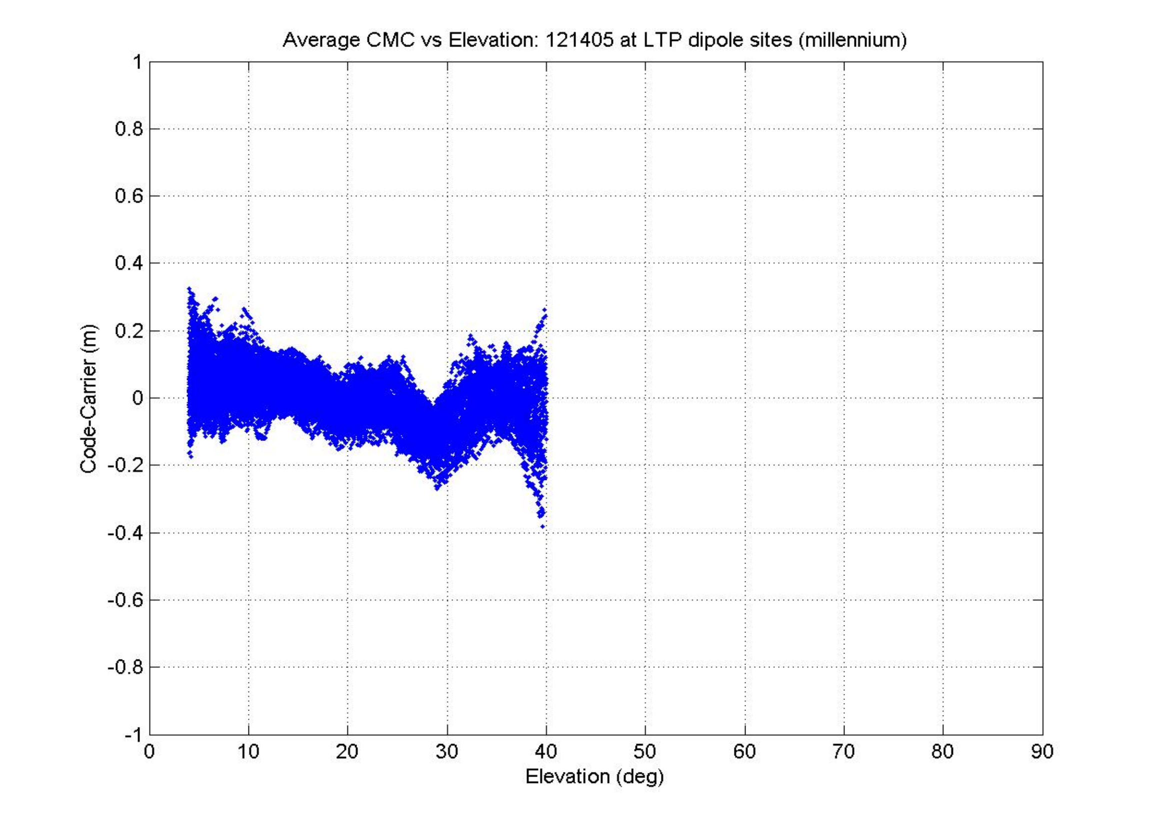
8.9.3.6.9 Dipole Error Characterization versus Azimuth and Elevation



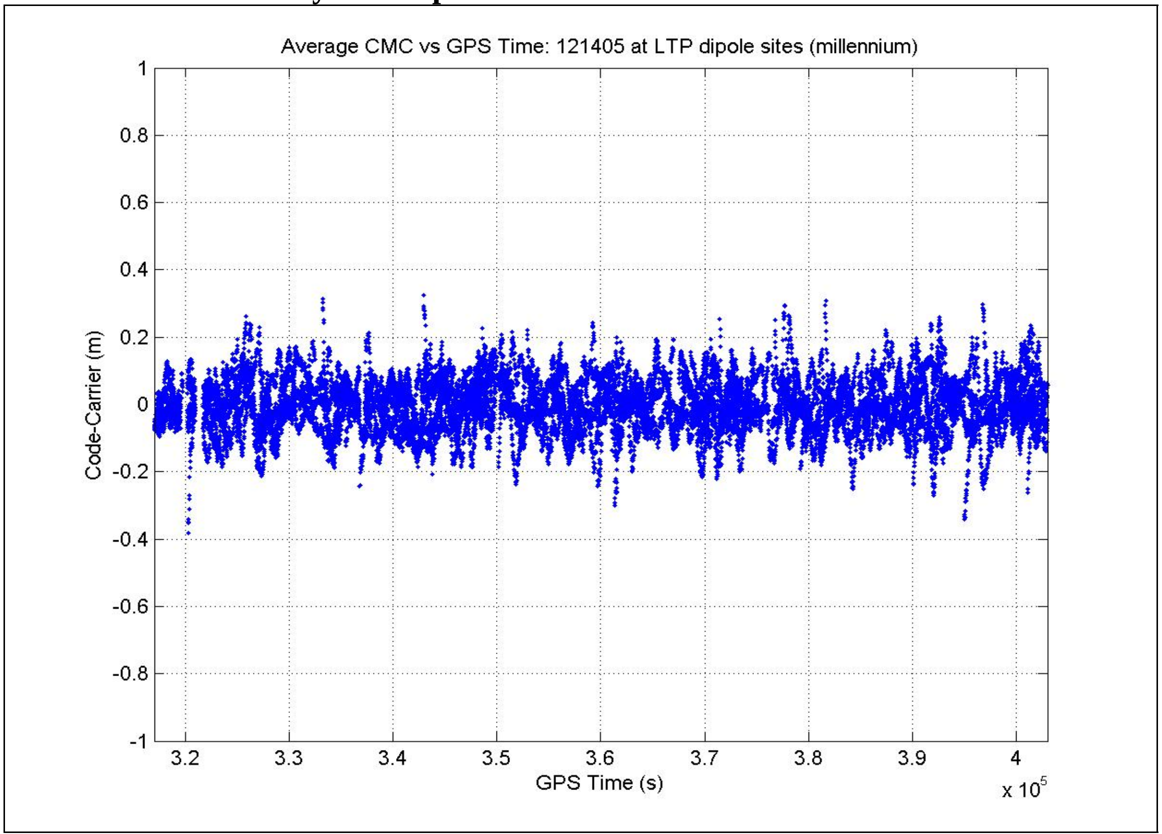
8.9.3.6.10 December System Dipole Number of Samples versus Elevation



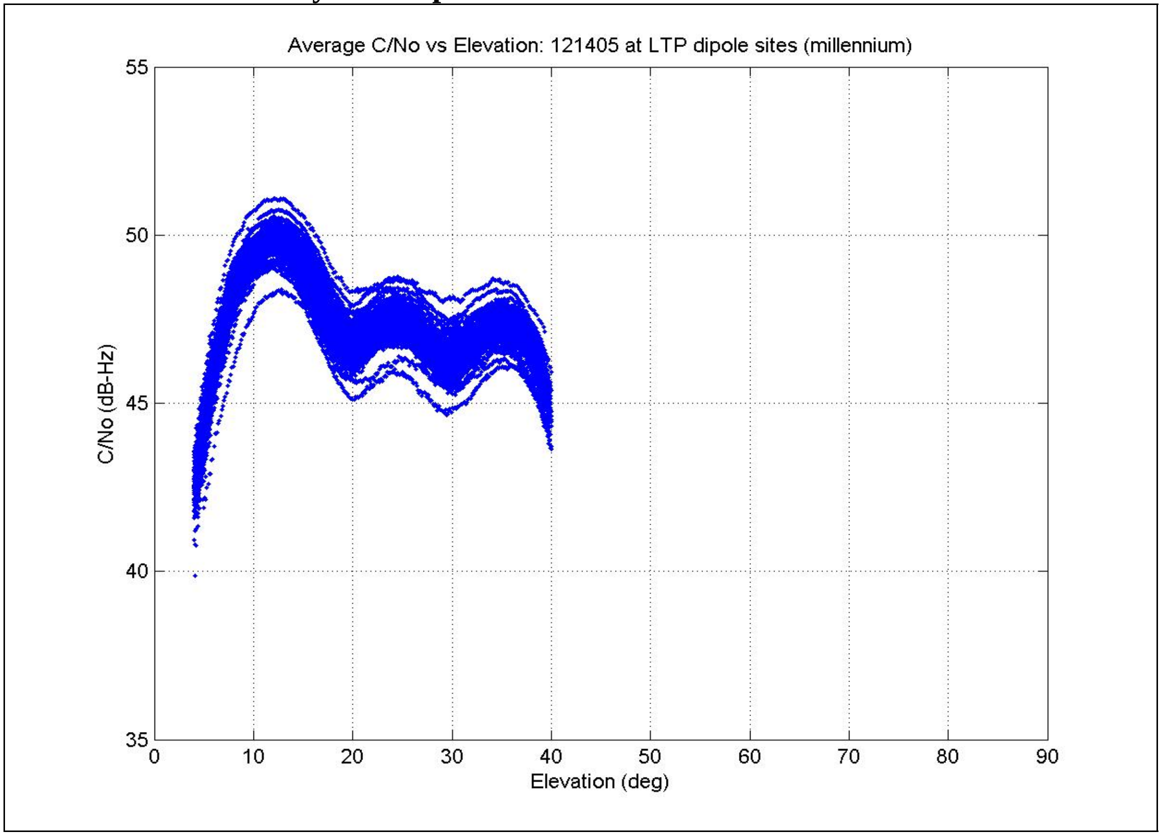
8.9.3.6.11 December System Dipole CMC versus Elevation



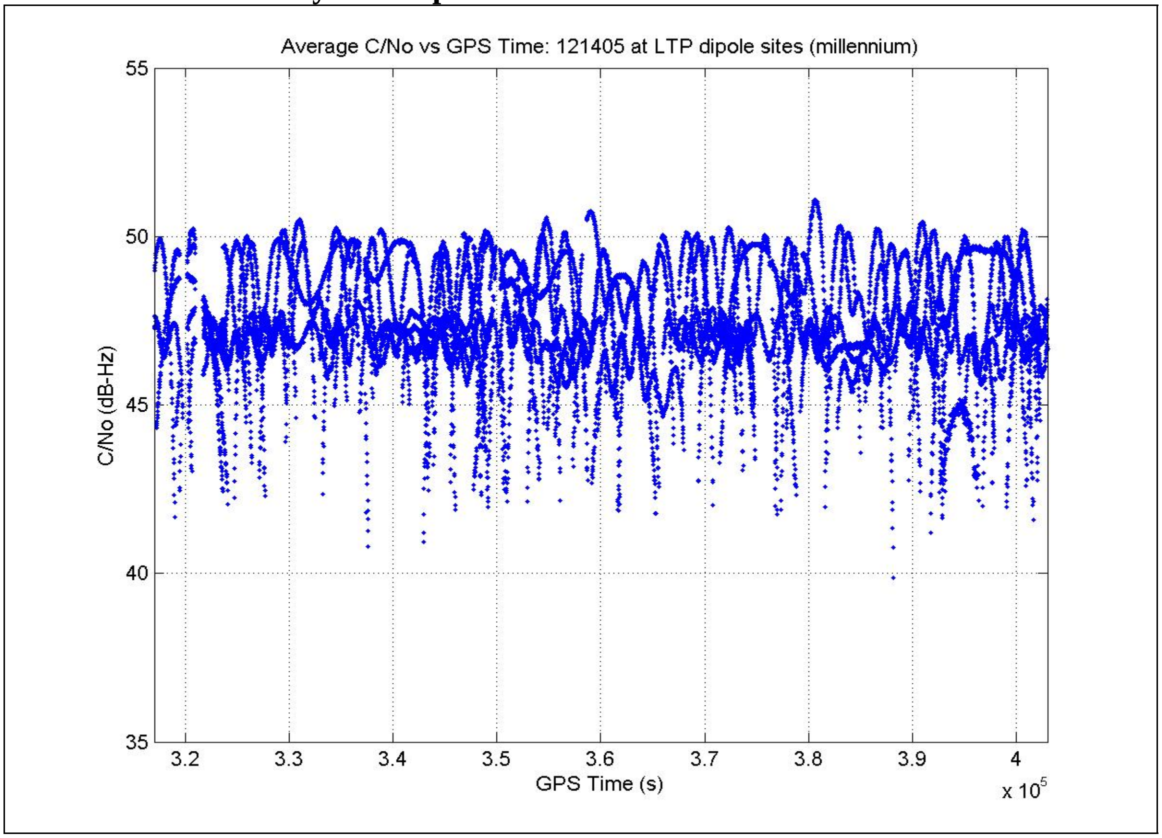
8.9.3.6.12 December System Dipole CMC versus Time



8.9.3.6.13 December System Dipole Carrier to Noise versus Elevation

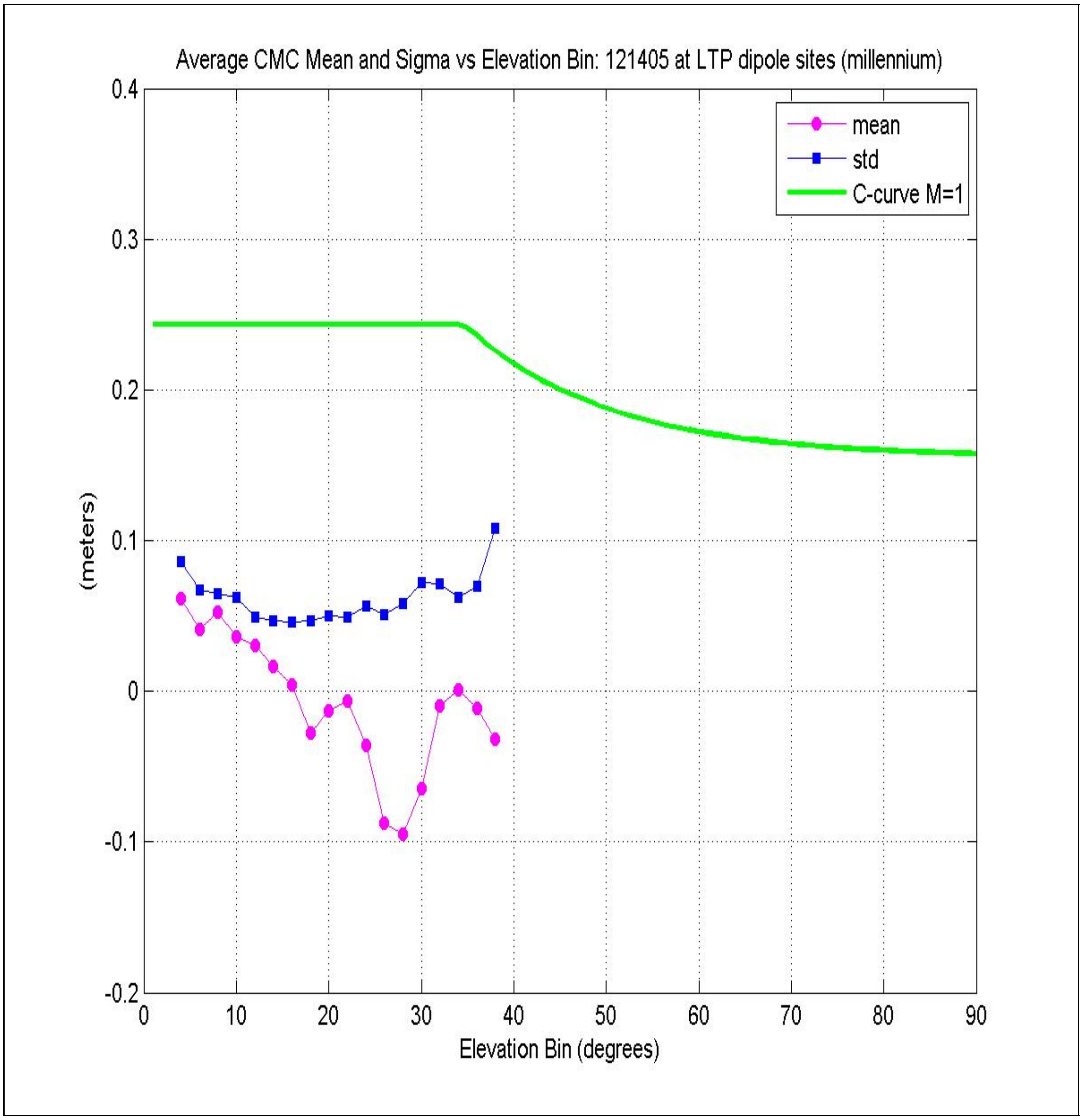


8.9.3.6.14 December System Dipole Carrier to Noise versus Time

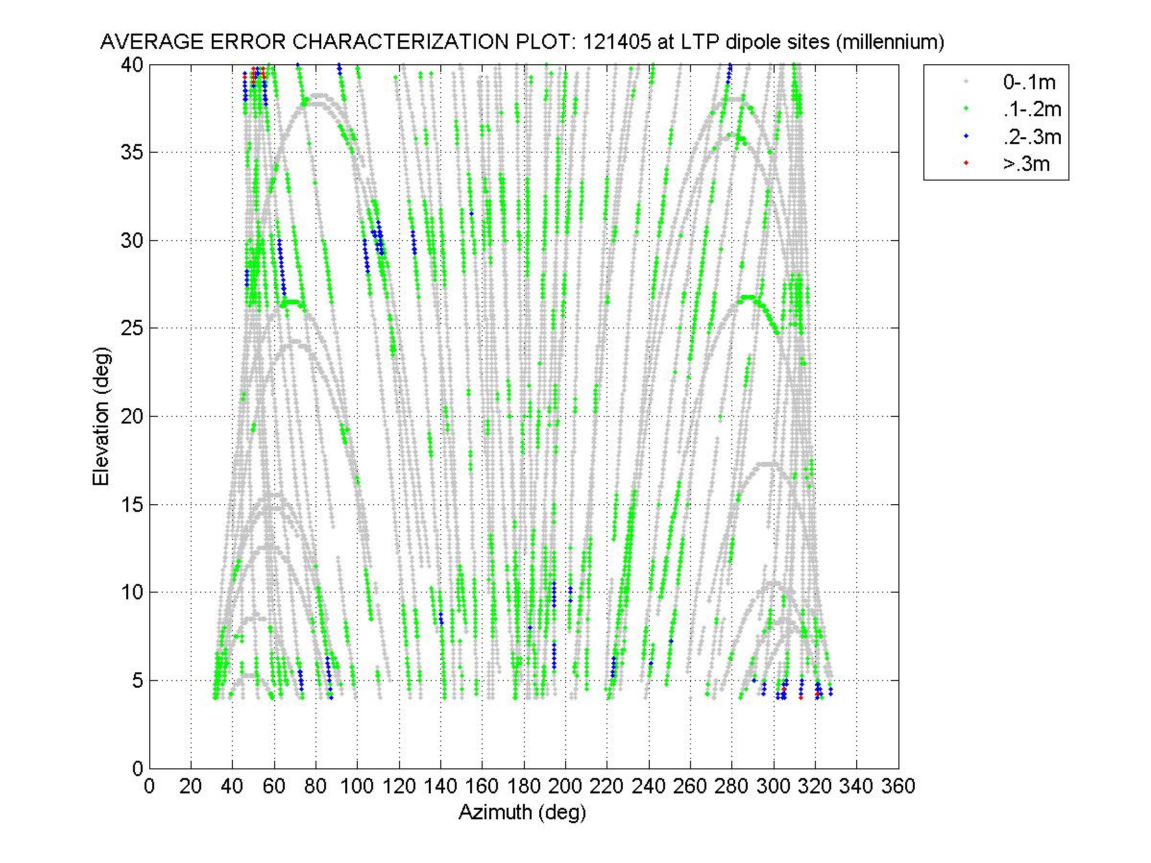


8.9.3.7 December HZA Status and CMC (System Average) (multiple)

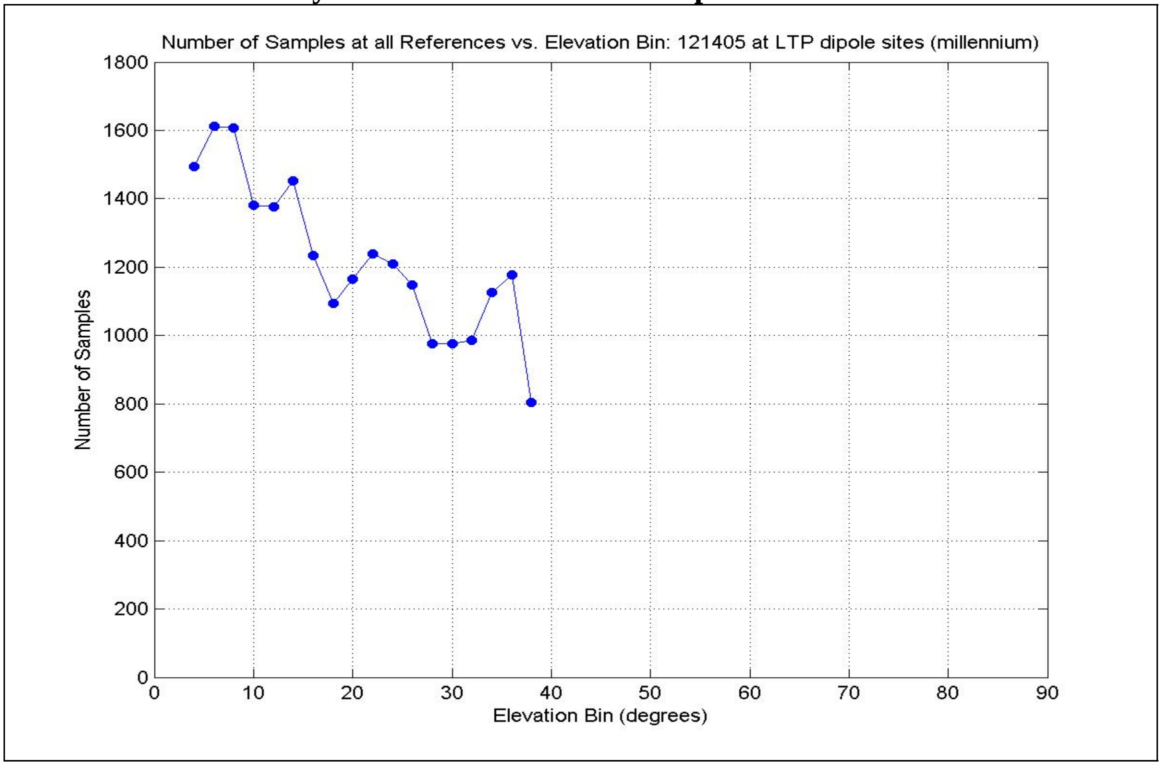
8.9.3.7.1 December System HZA CMC Standard Deviation and Mean versus Elevation



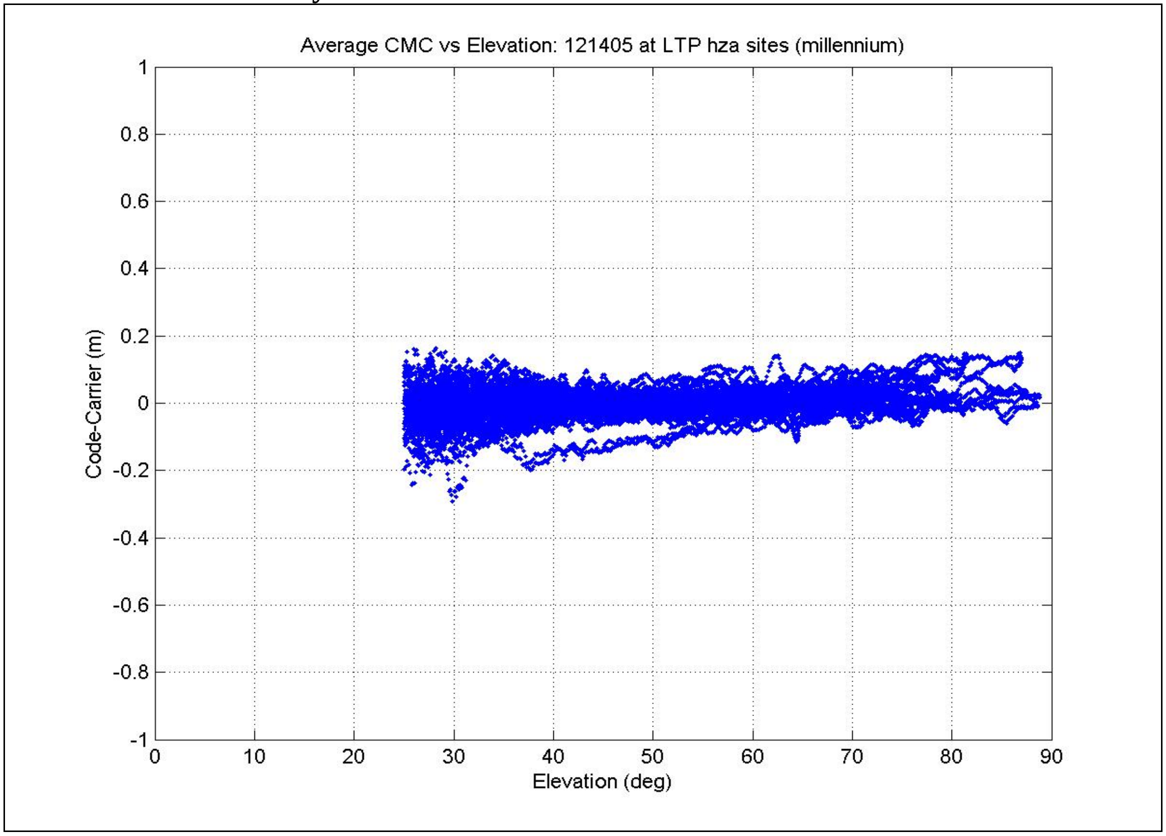
8.9.3.7.2 December System HZA Error Characterization versus Azimuth and Elevation



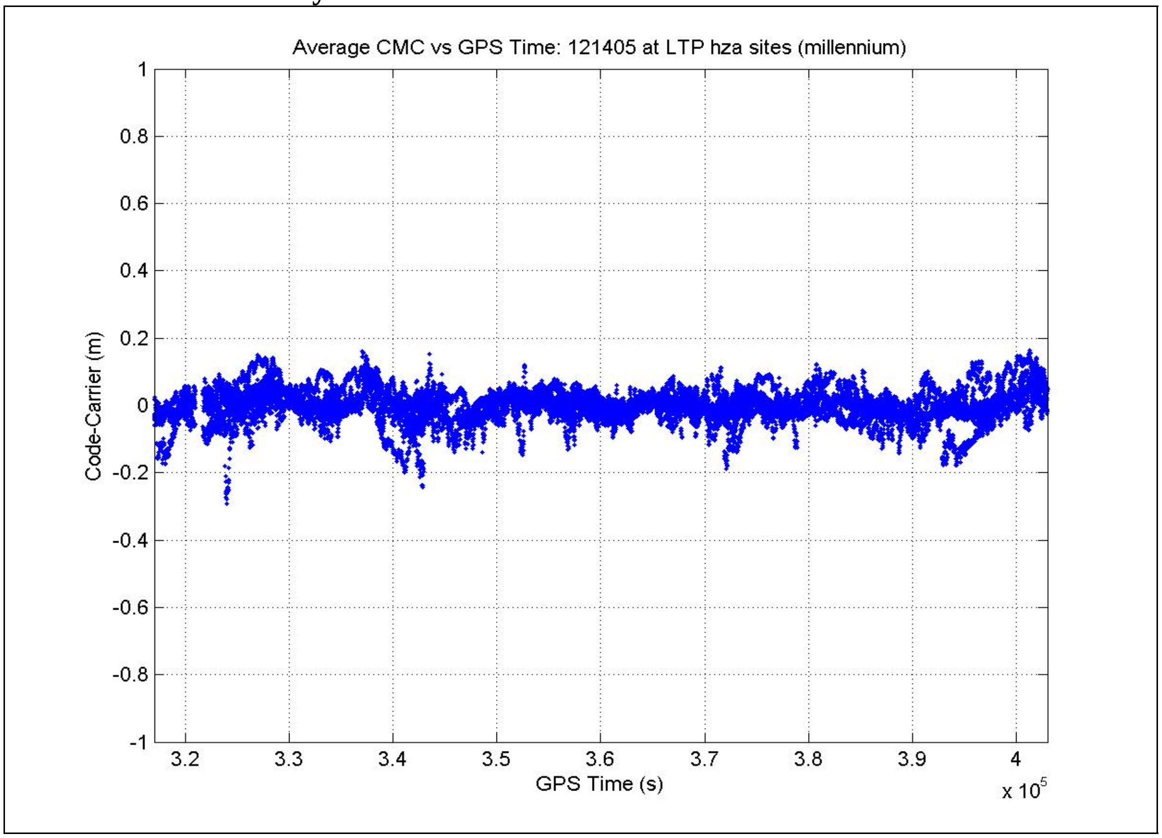
8.9.3.7.3 December System HZA Number of Samples versus Elevation



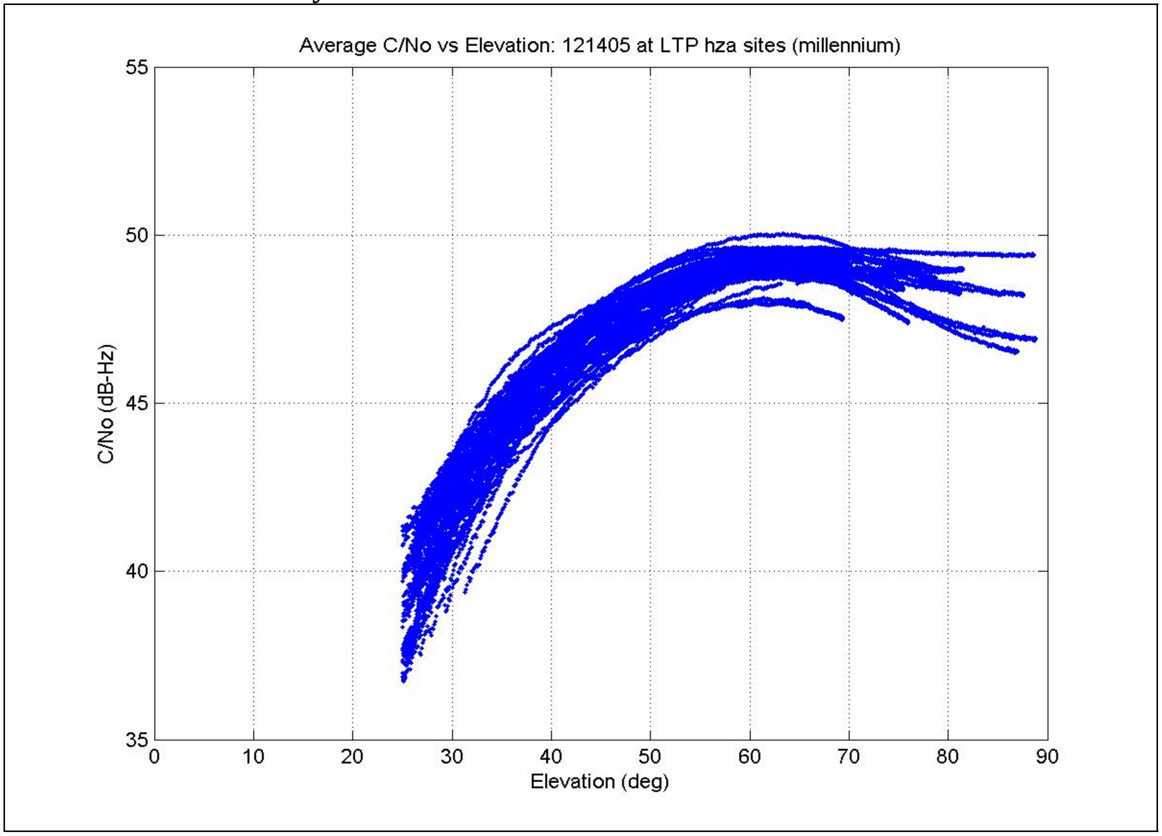
8.9.3.7.4 December System HZA CMC versus Elevation



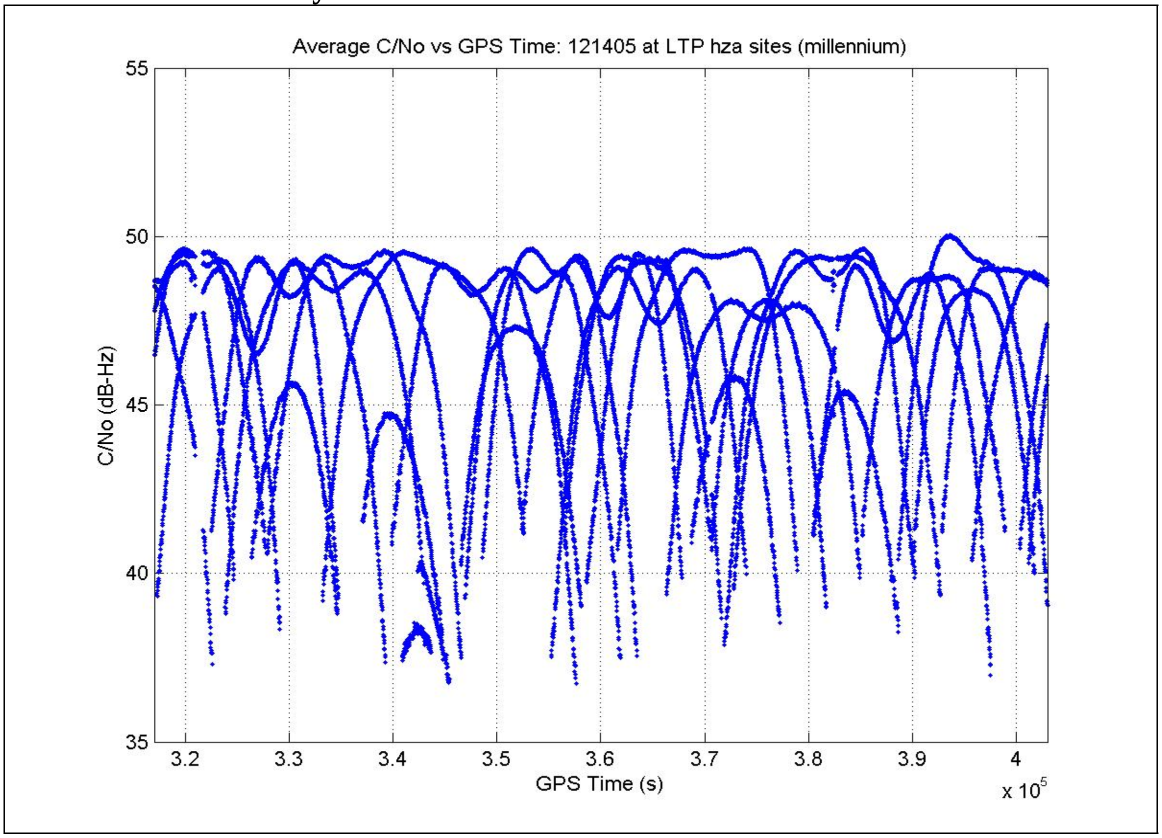
8.9.3.7.5 December System HZA CMC versus Time



8.9.3.7.6 December System HZA Carrier to Noise versus Elevation



8.9.3.7.7 December System HZA Carrier to Noise versus Time



9 Glossary of Terms and Acronyms

A

ACY
Atlantic City International Airport.. i
AOA
Air Operations Area.. i

B

B-value
An estimation of the pseudorange correction (PRC) error 21

C

CDI
Course Deviation Indicator.. 10
CMC
Code Minus Carrier.. 1
CNO
Carrier to Noise Ratio.. 17
CPU
Central Processing Unit.. 7
CRC
Cyclical Redundancy Check………….…………………………………………17

D

DQM
Data Quality Monitor……………………………………………………………….17

E

EPOL
Elliptically Polarized.. 15

F

FAA
Federal Aviation Administration.. i

G

H

I

L

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11 Key Contributors and Acknowledgements

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